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LIFE HISTORY OF THE CUI-UI, *CHASMISTES CUJUS* COPE, IN PYRAMID LAKE, NEVADA: A REVIEW

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ABSTRACT.—The cui-ui, *Chasmistes cujus* Cope, a member of the sucker family and endemic to Pyramid Lake, Nevada, is listed as endangered by the U.S. Fish and Wildlife Service. Cui-ui was once a major source of sustenance for native Americans, who have inhabited the Lahontan region for at least 11,000 years. The Northern Paiutes developed sophisticated fishing technology to harvest this resource. The original distribution of cui-ui was the ancient Lake Lahontan complex, but as a result of climatic changes it was restricted to the Pyramid-Winnemucca-Truckee system by the turn of the 20th century. Transbasin water diversions (1905 to present) have resulted in further restrictions of habitat. The species is now limited to Pyramid Lake and the lower Truckee River. Reproduction is from hatcheries as well as limited natural reproduction. Females produce more than 40,000 2–mm eggs per year. The normal development is described from the unfertilized egg through 912 hours post-hatching, when the fry are actively feeding and approaching adult body form. The unusual feature of adult cui-ui morphology is the relatively large ventro-terminal mouth, with thin and obscurely papillose lips. Cui-ui grow slowly and may live 18 years or possibly much longer; females generally live longer and attain a greater size than males. The highest adult mortality probably occurs during spawning runs. At this time they are vulnerable to predation, stress, and sometimes environmental degradation. The highest larval mortality probably occurs from predation when they are planted or migrate into the lake. The trophic ecology of the species is poorly understood, but they are known to ingest algae and zooplankton. Spawning behavior is documented. At present, natural reproduction is probably still the limiting factor for the cui-ui population. Cui-ui composed less than one percent of the total fish in Pyramid Lake during 1975–1977. During 1982 the largest cui-ui spawning run (13,000) in recent years occurred. The activity of cui-ui in the lake closely resembles that of the Tahoe sucker being most active during the spawning season each spring. Cui-ui inhabit the inshore-benthic zone and the pelagic waters of Pyramid Lake (<46 m).

The cui-ui, *Chasmistes cujus* Cope, a member of the sucker family (Catostomidae), is present only in Pyramid Lake and the affluent lower Truckee River, Nevada (Fig. 1). Because of its limited range and depleted numbers, it is listed as endangered (Federal Register, Vol. 32/48, 11 March, 1967). Cui-ui until recently was an important food source for Northern Paiute, the native Americans who have inhabited the region for at least 11,000 years. Prehistorically the habitat of cui-ui consisted of the Lake Lahontan system, which reached its maximum size of about 22,300 km^2 some 13,000 years before present (BP) and inundated a large portion of northwestern Nevada. The cui-ui was present in Winnemucca Lake until the late 1920s or early 1930s (Fig. 2).

There is general agreement that the ecological devastation of the cui-ui's lake and river environment was caused in part by the Newlands Reclamation Irrigation Project (NRIP), which was authorized by the U.S. Congress in 1903. In 1905 Derby Dam was dedicated, and

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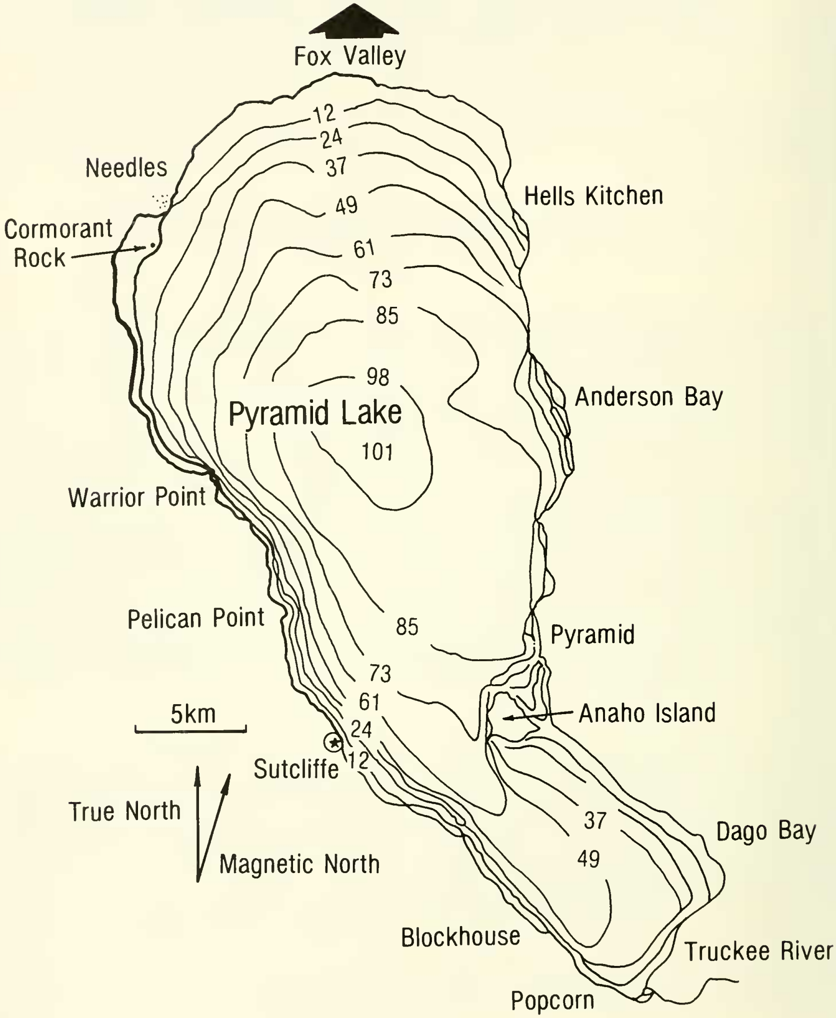

Fig. 1. Bathymetric map of Pyramid Lake, Nevada; depth contours are in meters at elevation 1154.9 m.

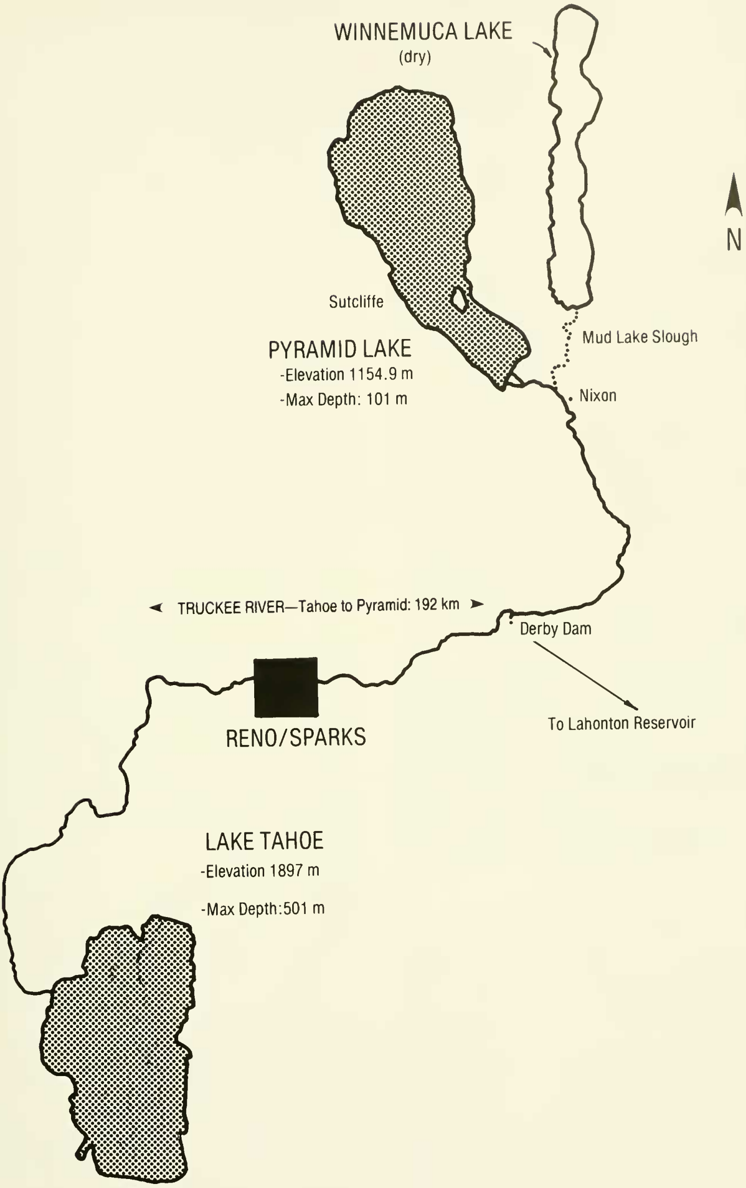

Fig. 2. The Truckee River–Pyramid Lake Ecosystem.

transbasin water diversion from the Truckee River to the Carson River system began. Lahontan Dam on the Carson River was completed in 1915, creating Lahontan Reservoir—the water storage impoundment for the NRIP. From 1915 to 1970 as much as half or more of the total flow of the lower Truckee River was diverted to the NRIP. Because of droughts and diversions, the level of Pyramid Lake declined more than 24.4 m from 1909 to 1968, Pyramid Lake increased in total dissolved solids (TDS) from about 3500 to 5500 mg/l, and Winnemucca Lake disappeared in 1938. A delta developed at the mouth of the Truckee River in the early 1930s that was virtually impassable to spawning migrations of cui-ui. Natural reproduction in the Truckee River was very limited for about 50 years (until the new Marble Bluff dam and the fishway became functional for cui-ui in 1982). However, during years of exceptionally high flow, natural reproduction may have been possible. Upstream, Siphon dam (washed out in 1958), and about 1 mile below it the original Marble Bluff dam (washed out in 1950) were also barriers to migrating cui-ui. Neither of these obstructions had functional fish ladders. The original Numana Dam also barred cui-ui migration.

It is our objective to synthesize information collected during the Pyramid Lake Ecological Study, conducted by W. F. Sigler & Associates Inc. during 1975–1978, with available data from agency reports and research publications to present an overview. It is hoped this paper will contribute to the knowledge of the cui-ui, and that its deficiencies will point out areas where additional research is needed.

HISTORICAL OVERVIEW

Cope (1883) first diagnosed and revised the genus *Chasmistes* and named a new species *C. cujus* from Pyramid Lake. In 1918, Snyder published the first life history information on *C. cujus* and other fishes of the Lahontan System; even at this early date Snyder considered the fate of the cui-ui to be uncertain. Sumner (1940) collected environmental and fishery data from Pyramid Lake and the Truckee River, compiled a chronology of the fishery, and stated that the major cause of the decline of the fishery was the transbasin diversion of Truckee River water.

T. J. Trelease, the first fishery biologist for the Nevada Department of Fish and Game (NFG), did preliminary work on the diet and reproduction of cui-ui (La Rivers 1962). Jonez (1955) and Johnson (1958) (both NFG biologists) worked with cui-ui during the 1950s conducting evaluations of cui-ui behavior and habitat. La Rivers made many observations over the years and developed a life history for cui-ui, incorporating information from previous workers.

Koch (1972, 1973) supplied information on life history, reproductive characteristics, and spawning behavior of cui-ui, Koch and Contreras (1973) advanced artificial hatching techniques, and Koch (1976) summarized available life history information. The U.S. Fish and Wildlife Service operated a cui-ui hatchery in 1974–75. Pyramid Lake Fisheries (PLF) has operated the David L. Koch Cui-ui Hatchery since 1977 and has further refined hatching and rearing techniques.

In 1971 the U.S. Department of the Interior (DI) reported the classification status of the cui-ui. Federal restoration of the species began in 1973 by the U.S. Fish and Wildlife Service (FWS) cui-ui recovery team. This team completed a Draft Cui-ui Recovery Plan in 1977 (Pyle et al. 1977). The 1982 revision of the original Cui-ui Recovery Plan was approved by the FWS and reviewed by DI (U.S. Fish and Wildlife Service 1983).

In 1975 the U.S. Bureau of Indian Affairs (BIA) funded studies on the fisheries of the Truckee River and Pyramid Lake. The results of the Pyramid Lake Ecology Studies, including data on cui-ui ecology, are presented in Sigler and Kennedy (1978). The results of the Truckee River studies are in preliminary FWS reports. McConnell, Galat, and Hamilton-Galat (1978) and Galat and McConnell (1981) discuss Pyramid Lake fish production in relation to potential changes in total dissolved solids (TDS).

In the early 1960s the NFG developed plans for a fishway that would enable upstream migrating fish to bypass the delta and enter the lower Truckee River. The plans were submitted to the Fleischmann Foundation, Reno, Nevada, but the facility was not funded because the Foundation could be given no assurance of a water right. The NFG, along with the FWS and the U.S. Bureau of Reclamation

(BOR), then developed plans for a larger and more elaborate facility. The NFG also lobbied with state and national agencies for the Washoe Project Act, which made funding possible (T. J. Trelease personal communication 1984). The Washoe Project Act was made much more salable by the earlier development, largely by NFG, of highly successful Lahontan cutthroat trout, *Salmo clarki henshawi*, fishery.

In 1975 BOR completed the Marble Bluff Fishway. The FWS operates the Marble Bluff facility and monitors spawning migrations of cui-ui and Lahontan cutthroat trout. Data collected by FWS on cui-ui spawning populations in the lake and fishway are presented by U.S. Fish and Wildlife Service, Nevada Department of Fish and Game, California Department of Fish and Game (1976), Ringo and Sonnevil (1977), and Sonnevil (1977a, 1977b, 1978, 1981). The age structure of cui-ui in 1978 was determined by Robertson (1979). Scoppettone et al. (1981, 1983, and G. Scoppettone personal communication 1983) studied the spawning behavior and habitat requirements of cui-ui in a natural side channel of the lower Truckee River.

Research on the habitat and ecology of fish species in Pyramid Lake was conducted by Vigg (1978a). Vertical distribution patterns and relative abundance are reported (Vigg 1978b, 1980, 1981).

Research on the effects of increasing levels of TDS on cui-ui was initiated by Earl Pyle of FWS during 1975–1978. Chatto (1979) presented preliminary data on hatching success of cui-ui eggs in various proportions of Pyramid Lake water. Lockheed Ocean Sciences Laboratories (LOSL) (1982) studied the effects of various levels of TDS on the embryos, larvae, and juveniles of cui-ui.

T. J. Trelease first reared larvae in 1947, and Kay Johnson and Ivan Young (all NFG personnel) raised them to adult size—about 31 cm. Koch et al. (1979) estimated 91.6% hatching success in controls during nitrogen-species bioassays. However, they were unable to obtain definitive results on toxicity because of high mortality in all treatments and controls. Koch (1981) conducted preliminary temperature tolerance studies of cui-ui embryos and larvae.

Various morphological studies have been conducted on catostomid fishes, including cui-ui. Nelson (1948, 1949, 1961) studied the comparative morphology of the Weberian apparatus, the opercular series, and the swim bladder, respectively. Miller and Evans (1965) studied the external morphology of the catostomid brain and lips. Snyder (1981a, 1981b, 1983) studied larval development of cui-ui, mountain sucker (*Catostomus platyrhynchus*), and Tahoe sucker (*Catostomus tahoensis*) and prepared a key for their identification. Miller and Smith (1967, 1981) discuss the paleohistory, systematics, distribution, evolution, and status of each species of *Chasmistes*.

Donald R. Tuohy, Nevada State Museum, Carson City, has conducted extensive archaeological studies within the Pyramid Lake region; however, the data are largely unpublished. Archaeological finds at Pyramid Lake are reported by Ting (1967) and Tuohy and Clark (1979). Hattori (1982) studied the archaeology of the Winnemucca Lake area and relates the importance of aquatic resources, including cui-ui, to human prehistoric habitation. The importance of the fishery, especially cui-ui, to the native Americans is discussed by Bath (1978). The ethnographic record of Pyramid Lake Northern Paiute fishing is presented by Fowler and Bath (1981). Follett (1963, 1974, 1977, 1980, 1982) has studied cui-ui remains in aboriginal deposits. Stewart (1941) discusses the culture element distributions of the Northern Paiute.

PROCEDURES

Cui-ui were captured with variable mesh bottom-set gill nets in Pyramid Lake and at the Marble Bluff facility on the Truckee River. Vigg (1981) presents a description of fish sampling design and methodology. For age and growth data, fish were weighed to the nearest gram, measured (nearest mm), and sexed internally, except at spawning time. Scales, opercula, otoliths, and fin rays were taken to compare accuracy of aging using different bony parts. The length-weight relationship is expressed by the formula $W = aL^b$ (Sigler 1951), where W = weight (g), L = fork length (cm), and a and b are constants. The value of the constants (a and b) are calculated by the method of least squares using log transformations of weight and length ($\log W = \log a + \log b$ length). Validity of the aging method was determined by criteria suggested by Van Oosten (1923, 1929, 1944) and Hile (1941). To avoid possible bias, scales and other bony parts were first read without knowledge of the size of the fish. They were read at least three times. The length of body–bony part relationship was calculated according to Tesch (1971). The condition factor $K = Wx10^5/L^3$ was calculated according to Carlander (1969), where W = weight (g) and L = fork length (mm). Age and growth calculations were accomplished using a computer program (Nelson 1976).

Cui-ui eggs and embryos used in this study were obtained from the David L. Koch Fish Hatchery. They were collected at regular intervals postfertilization and preserved in both Bouin's solution and Puckett's fixative. Serial sections of the entire embryo were cut at 8–10 micrometers and stained with hematoxylin and eosin and Mallory's Triple Stain. Embryos to be sectioned were chosen from among the best preserved of 12–15 specimens from each sample. In addition to sectioned material, whole mounts were also used, ranging in age from 9 to 912 hours post-hatching (Bres 1978).

There were 19 water sampling stations located along 4 transects designed to represent the horizontal areas of the lake and to facilitate measuring the influence of the river upon the system. Stations were sampled on a monthly basis from November 1975 through October 1977. Conductivity, oxygen, pH, temperature, and turbidity in relation to time, depth, and location were measured in the field with an InterOcean probe (Model 513D). Measurements were taken at 2-m intervals from the surface to 22 m and at 5-m intervals from 25 m to the bottom. Conductivity measurements were standardized to 25 C. Water samples were collected for analysis of major chemicals and trace elements the third week of every month from January through December 1976 and again in April and September 1977. Samples to be tested for nutrients were collected at least once a month from January 1976 through December 1977. Water samples were collected at the surface (1m), middepth, and bottom levels at the midpoint of each of three transects (Lider 1978). Analyses were done by the Desert Research Institute Water Chemistry Laboratory.

RANGE AND DISTRIBUTION

Four recent species of *Chasmistes* are known: *C. cujus* Cope, *C. liorus* Jordan, *C. brevirostris* Cope, and *C. muriei* Miller and Smith; the latter species, known from a single collection, is now extinct. Two additional extinct species, *C. batrachops* Cope and *C. spatulifer* Miller and Smith, are known only from the fossil record. Miller and Smith (1981) discuss the distribution and evolution of the various forms of *Chasmistes* (Table 1).

Chasmistes is a lacustrine sucker; all living species and most extinct forms are associated with lake systems. However, the oldest known form, *Chasmistes* sp. from the fluvial beds of the Miocene Deer Butte Formation in Oregon, is an exception (Miller and Smith 1981).

The Pyramid Lake cui-ui population is the last remaining pure species of the genus; the other species have considerable hybridization and introgression with *Catostomus* spp. (Miller and Smith 1981). Cui-ui inhabited Lake Lahontan during the late Pleistocene period (Fig. 3). At its maximum extent, approximately 12,000 years BP, Lake Lahontan covered about 22,300 km^2 and received drainage from about 117,000 km^2 (Russell 1885). Fossil cui-ui have been discovered in the Carson Desert, which was once contained in the largest basin of Lake Lahontan; additional *Chasmistes* sp. fossils have been found in the Honey Lake basin to the northwest (Miller and Smith 1981). As Lake Lahontan desiccated during the last 10,000 years, its contiguous basin became nine remnant lakes. Cui-ui persisted for variable lengths of time in these remnant waters until desiccation caused extinction of most populations. Cui-ui was not present in Walker Lake during historical times. This idea is confirmed by the work of Spencer (1977) and Benson (1978a), which indicated Walker Lake was dry sometime during the period 9050 to 6400 years BP.

During historic times cui-ui lived in both Pyramid and Winnemucca lakes and spawned in the Truckee River as far upstream as just below Reno (Snyder 1918). When Derby Dam was completed in 1905, spawning cui-ui

TABLE 1. The geographic distribution of recent and fossil species of *Chasmistes* (Miller and Smith 1981).

RECENT SPECIES

Common name	*Scientific name*	*Drainage basin*	*Present range*
Cui-ui	*C. cujus* Cope	Lahontan	Pyramid Lake, Nevada
June sucker	*C. liorus* Jordan[A] *C. l.* *C. l. mictus*	Bonneville	Utah Lake, Utah
Shortnose sucker	*C. brevirostris* Cope	Klamath River	Upper Klamath Lake, Oregon
Snake River sucker	*C. muriei* Miller and Smith	Snake River	Extinct[B]

FOSSIL SPECIES

Scientific name	*Geologic epoch*	*Geologic formation*	*Paleohabitat*
Chasmistes sp.	Miocene	Deer Butte, OR	Fluvial
C. spatulifer Miller & Smith	Pliocene and Pleistocene-Recent	Glenns Ferry, ID to Adrian, OR	Lake beds
Chasmistes sp.	Pliocene	Glenns Ferry, ID	Lake beds
Chasmistes sp.	Pliocene	Secret Valley, CA	Lake beds
Chasmistes sp.	Pliocene	Honey Lake sediments	Lake Lahontan
Chasmistes sp.	Pliocene	Calcareous sands	Mono Lake
Chasmistes sp.	Pliocene	Teevimom, WY	——
C. batrachops Cope	Pleistocene - Recent	Fort Rock Basin, OR	Fossil lake
Chasmistes cf. *C. batrachops*	Pleistocene - Recent	White Hills, CA	China Lake
C. batrachops	Pleistocene - Recent	Duck Valley, NV	Pleistocene Lake
Chasmistes cf. *C. liorus*	Pleistocene - Recent	Black Rock Canyon, UT	Lake Bonneville
C. cujus	Pleistocene - Recent	Pleistocene gravels, Fallon, NV	Lake Lahontan
C. brevirostris	Pleistocene - Recent	Indian middens, Klamath Lake, OR	Klamath Lake

A. *Catostomus fecundus* - *Chasmistes liorus* × *Catostomus ardens*
B. Based on a single collection from the Snake River below Jackson Lake Dam.

were restricted to the river below that point. As water was diverted to the NRIP via the Truckee Canal, the water level in Winnemucca and Pyramid lakes dropped. Winnemucca Lake dried in 1938. Pyramid Lake and the affluent lower river is the only remaining habitat for cui-ui.

EMBRYOLOGY

Koch (1972, 1976) did limited work on the larval development of cui-ui, finding many similarities to the development of the white sucker, *Catostomus commersoni*, as described by Stewart (1926). Long and Ballard (1976) document the stages of embryonic development of the white sucker and cite diagnostic structural characteristics for each stage. They also review previous work on embryology of other fishes within the order Cypriniformes. Snyder (1983) found that sequences of developmental events are nearly equal for cui-ui, Tahoe sucker, and mountain sucker and typical at least for the tribe Catostomini. However, the latter two species, at any given size, are slightly more developed than cui-ui. The following is a detailed discussion of the embryological development of the cui-ui in a 13 C environment (Bres 1978).

Egg-Embryos

The unfertilized egg of the cui-ui is about 2 mm in diameter and is surrounded by a noncellular chorion. It has one micropyle at the animal pole. After fertilization, during a process known as water hardening, the eggs

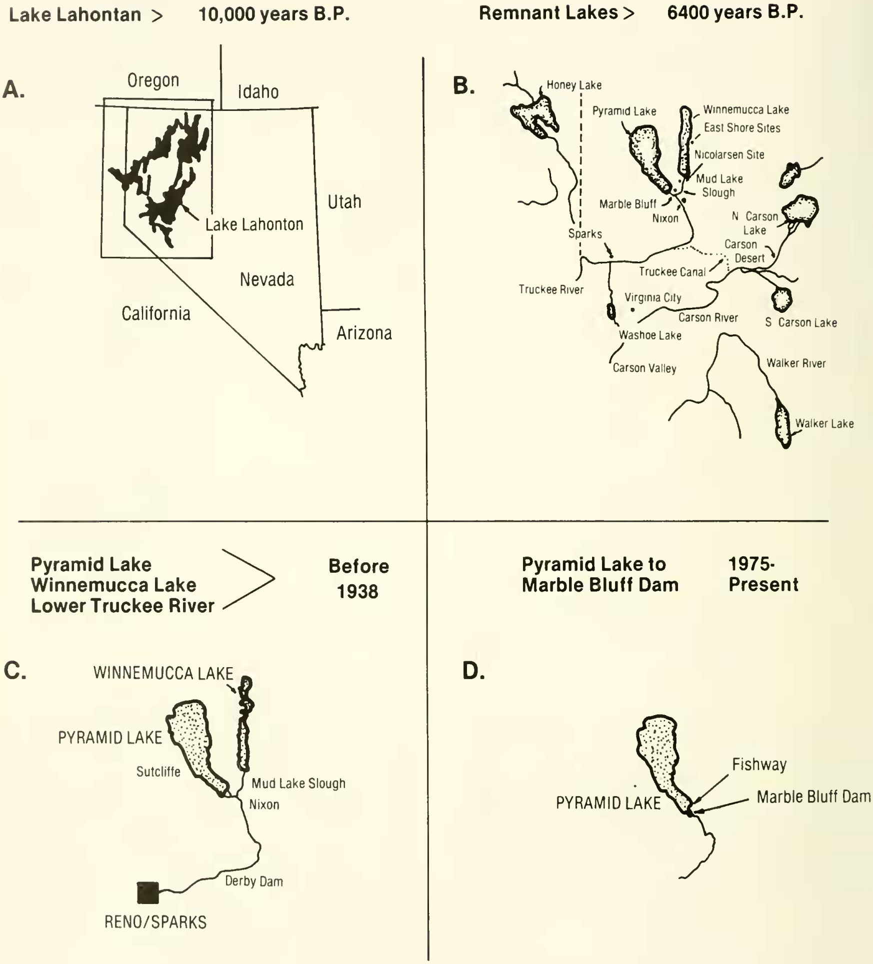

Fig. 3. Decrease in the range of the cui-ui from Lake Lahonton times to the present.

imbibe water and swell to 3 mm. Koch (1976) recorded an 83% increase in egg volume during water hardening, which took 39 minutes. Trelease (personal communication 1984) recorded 75% increase during water hardening and a time of 60 to 75 minutes. The blastodisc appears at 6 hours postfertilization, 0.5 mm in diameter, and is elevated above the surface of the egg at the animal pole. By 18 hours postfertilization, 8 blastomeres are present, with an exponential increase in number thereafter. After 19 hours, "giant" nuclei are seen associated with the syncytial cells of the yolk sac. The marginal periblast is at the periphery of the blastoderm.

At 48 hours postfertilization, the first distinction between the three germ layers is apparent. The neural plate has formed, along with a thickened precursor to the neural tube. The notochord and somites are present.

At 96 to 120 hours, the neural tube and notochord are well developed. Myotomes have differentiated from somites, and the dorsal fin fold has begun to develop. The pronephric ducts are formed anteriorly but are undifferentiated posteriorly. The gut has no lumen and is incomplete posteriorly, and the cloaca has not yet formed.

Anterior neural crest migration occurs at 144 to 168 hours. The diencephalon exhibits cruciform shape. The optic vesicles have developing lenses, and the opticoel joins the diocoel. Auditory vesicles are also present. Myoblasts the length of one somite can be seen. The coelomic cavity is developing between the somatic and splanchnic mesoderm.

At 192 hours cranial ganglia V, VII, and X are visible. Presumptive medulla is developing, and the lateral ventricles are present. The pronephric duct has increased in length, and tubule development is beginning. The liver diverticulum and developing gut are visible. Vitelline circulation is well developed, and the dorsal aorta and postcardinal veins are visible. Precursors of the pigmented retina (a single layer of cells) and the neural retina are forming in the eye. At 13 C hatching occurs at 216 hours.

Larvae

At hatching cui-ui are white and threadlike in appearance, 6 to 7 mm in length, without functional vision, and have only limited powers of locomotion (Table 2 and Fig. 4).

TABLE 2. Time sequence of cui-ui development at 13 C.

AGE (Hours postfertilization)	DEVELOPMENTAL STAGE
0	Unfertilized ovum
6	Formation of blastodisc
18	Eight-cell stage
19	Early blastula
48	Early neurulation, somites present
96 to 120	Neurulation complete, organ development begins
192	Well-developed circulation, appearance of retinal pigment
216	Hatching
(Hours post-hatching)	
9	S-shaped heart
26 to 31	4 pairs of gill arches, optic chiasma forms, secondary reopening of gut begins
51 to 56	6 pairs of gill arches, recanalization progresses to foregut
72	Extensive nerve development, spinal cord differentiated, internal melanophore development
84	Development of lateral line system and external melanophores
120	Begin directional swimming
312	Functional mesonephros, 5 functional gill arches
384	Mouth open, eyes functional, first development of swim bladder
672	Yolk completely absorbed, functional gut
912	Fry actively feeding, approaching adult body form

Central Nervous System.—The anterior curvature of the brain is noted 26 to 36 hours (post-hatch). Considerable nerve development has occurred by 72 hours. The cerebellum is still relatively small compared to the large medulla. The neural tube has differentiated into a spinal cord, and both gray and white matter are present. At 84 hours the potential neurohypophysis of the pituitary is developing in the brain. The III and IV ventricles are present, with the Aqueduct of Sylvius connecting them; the region of the epiphysis is also beginning to develop. Spinal ganglia

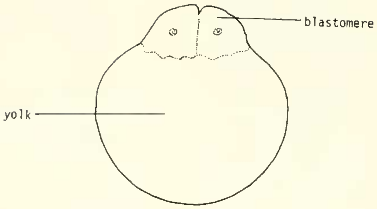

Fig. 4a. 6 hours postfertilization

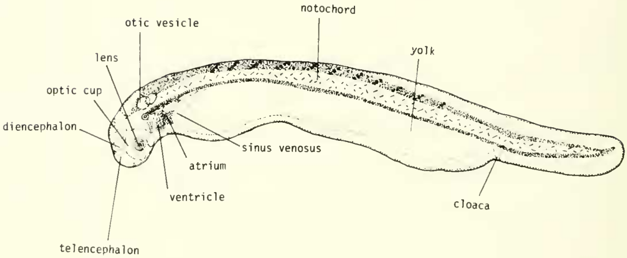

Fig. 4b. 9 hours post-hatching

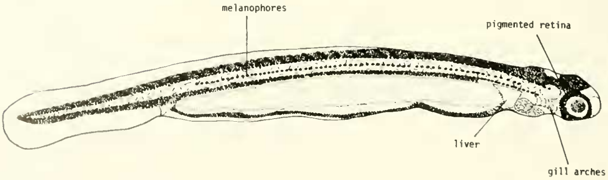

Fig. 4c. 4.5 days post-hatching

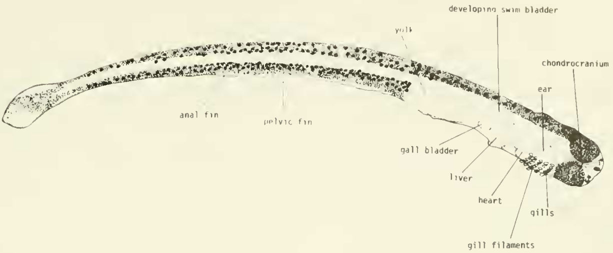

Fig. 4d. 21 days post-hatching

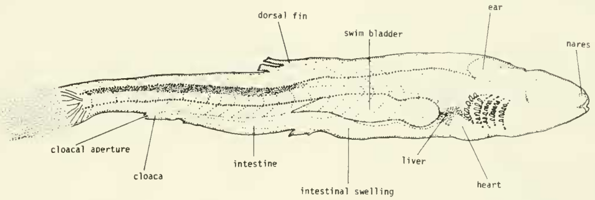

Fig. 4e. 38 days post-hatching

Fig. 4. Embryonic stages of development of the cui-ui.

are visible along the spinal cord. At 384 hours the epiphysis continues to develop. The pituitary and hypothalamus are visible, although no differentiation has occurred in the pituitary. Motor neurons are well developed in the mesencephalon. At 504 hours the developing chondrocranium is visible.

Eye.—The optic cup and retina continue to develop after hatching occurs. The optic chiasma is first observed at 26 to 31 hours (post-hatch), with the optic nerve connected to the retina. The horseshoe-shaped retina, derived from the optic cup, is apparent at 51 to 56 hours. At this time the oculomotor nerve is visible, extending from the brain to the eye region. By 72 hours the lens is present and the pigmented retina is represented by a thin layer; however, no differentiation has occurred in the sensory portion of the retina. Presumptive cornea has formed by 84 hours, and differentiation in layers of sensory retina has occurred. The optic nerve is attached to the retina. Extrinsic ocular muscles are well developed. By 120 hours, heavy pigmentation has been laid down on the retina. After 384 hours the pigmented iris, cornea, lens, and many sensory layers of the retina are visible. The eyes are functional and capable of movement.

Ear and Lateral Line.— Seventy-two hours post-hatching, the otic vesicle, the rudiment of the inner ear, begins to develop. The first complete distinction between the dorsal sacculus and the central utriculus takes place in the otic vesicle at 84 hours post-hatching. At this time the first indication of lateral line system development occurs. By 168 hours the otic vesicle is well developed. After 384 hours of larval development, the otic capsule has divided into 3 parts, the latter part being completely closed off. Otoliths are visible in the inner ear, and the cranial nerves that supply the ear are visible. The vestibular ganglia has developed outside the otic capsule from the stato-acoustic nerve (VIII).

Olfactory Sense and Taste Buds.—By 20 hours the olfactory placodes are well developed in the anterior portion of the head. The neural connection of the nasal placode to the brain (olfactory nerve) is visible by 26 to 31 hours. By 168 hours the olfactory organ has developed from the nasal placode. By 384 hours indentations are forming at the site of the future external nares. The mouth is open, and developing taste buds are visible in the mouth and gills by 384 hours. These are very abundant on the head, mouth, and gills of adults and compensate for incomplete development of the internal nares.

Gills.—Four pairs of gill arches are visible at 26 to 31 hours. The aortic arches leave the center of the gill arch to fuse together and open into the conus arterious. At 51 to 56 hours six pairs of gill arches are present and the gill cleft is developing. By 60 hours each of the six pairs of well-developed gill arches has a central core, the aortic arch. By 72 hours the aortic arch has increased substantially in size. At 84 hours the first gill cleft has opened. By 312 hours the 6 primitive gill arches have been reduced to 5 functional gill arches, the definitive adult condition. Each arch has at least 3 filaments composed of loops of capillaries. After 384 hours of development, gill filaments are evident, as are gill cartilages associated with muscles for moving the gills.

Heart.—The S-shaped heart is visible 9 hours post-hatching. After 20 hours the endocardial cushion, which is the precursor to valve development, is forming in the atrioventricular canal. Separation between endocardium and myocardium is pronounced by 56 hours post-hatching. The heart and associated vessels are well developed by 72 hours. Cardiac jelly is visible after 82 hours. After 120 hours all 4 chambers of the heart and the atrio-ventricular canal are visible. After 312 hours the muscular wall of the heart is well developed and the ventricle has become trabeculated. By 384 hours all blood vessels contain eosinophilic plasma.

Muscle.—Myotomes and myocommata are well developed by 9 hours. By 26 to 31 hours connective tissue is present in the myocommata. At 72 hours myofibrils appear as ribbons around the periphery of the muscle cells; this conforms to the standard configuration of the adult fish.

Skeleton.—After 20 hours the sites of the future chondrification of the ribs are visible as individual swellings along the dorso-lateral intersegmental myosepta. By 51 to 56 hours condensation is beginning to form the initial skeletal elements. The trabeculae of the chondocranium are visible, although they are not true cartilage but simply condensations of the mesenchyme. After 312 hours a large number of caudal rays are present. At 384 hours cartilage is present in the gill arches, opercula, and the roof of the mouth (precursor to palate).

Liver and Pancreas.—The liver primordium is well developed by 20 hours. At 26 to 31 hours the sinus venosus has been displaced to a crescent shape at the side of the liver. The liver primordium is well developed by 84 hours; a pancreatic rudiment is visible next to the intestinal swelling. The liver has an adult pattern of organization and is functional by 384 hours. The pancreas is forming lobules that will later spread out forming the adult diffuse pancreas. The gall bladder is visible; bile and pancreatic ducts are separate and fuse together at the entrance to the gut.

Kidney.—At 9 hours the pronephric ducts join with the intestine posteriorally to form the cloaca. By 26 to 31 hours, ciliated nephrostomes, the opening of the kidney tubule to the coelom, have developed in the pronephros, and coelomic fluid is pumped into the tubule. After 72 hours of larval development, kidney tubules are well developed in the pronephros. For the first time, the mesonephros and mesonephric tubules are visible. At 84 hours the mesonephric duct is visible, opening into the mesonephros and contacting the cloaca. By 312 hours the mesonephros has greatly enlarged, is very well developed, and has reached a functional state. At 672 hours the mesonephric duct and anus empty together into the cloacal aperture.

Alimentary Canal.—The pronephric ducts join with the intestine posteriorly to form the cloaca 9 hours post-hatching. The tiny, solid gut begins to form the loop of the intestinal swelling at about 20 hours. The larval cui-ui, like the adults, do not have a true stomach since it contains no glands. At 26 to 31 hours the secondary reopening of the gut begins, small in the liver mass but enlarging in the midgut region posterior to the liver. Mesenteries supporting the gut are visible. Absorptive cells are apparent in the yolk sac, and the mouth cleft is present. Further recanalization of the foregut is occurring at 51 to 56 hours. At

72 hours there are many secondary openings in the foregut. Also the lumen of the gut has greatly increased from 1 to 2 to 10 to 15 micrometers in diameter. At 84 hours the loops of the gut are beginning to form; early differentiation of the intestinal swelling and visceral cavity occurs. The pharyngeal cavity is open at 120 hours. After 384 hours the mouth is open, and many mucous-secreting cells are visible in the oral cavity. Material present in the pharynx suggests feeding, although some parts of the pharynx are still undifferentiated. The gut is broadly open and has developing longitudinal folds. From 384 to 504 hours the yolk sac is greatly diminishing in size. After 672 hours of larval development, the yolk is absent and the gut is functional, with food present in the intestine. By 840 hours the larvae are 20 to 25 mm long (Koch 1976). After 912 hours fry are actively feeding and the digestive tract is filled with food.

Integument and Pigmentation.—By 20 hours lateral fin folds are well developed, and many mucous secreting cells are visible in the ectoderm. Connective tissue is present in the dermis of the skin at 26 to 31 hours. After 72 hours the epithelium is still simple, and many secretory cells are present. Melanophore development is beginning internally. At 84 hours goblet cells are observed in the epithelium. Granular cells, filled with eosinophilic granules, are present, characteristic of the adult condition. Both small and large external melanophores are visible by 120 hours posthatching. At 384 hours mucous-secreting goblet cells are present in the skin.

Swimming.—After 18 hours the larvae are 8 to 9 mm long, and sudden bursts of energy constitute their initial swimming attempts; at 192 to 240 hours the larvae are 12 to 14 mm in length and continually swim at the surface (Koch 1976). Between 240 to 360 hours they swim to keep their position in the water column (Koch 1976). After 384 hours the pneumatic duct enters the gut from the developing swim bladder, and at 504 hours the swim bladder is clearly visible. The swim bladder has increased in size during 672 hours.

Identification.—Larval and juvenile cui-ui are sometimes difficult to identify in Pyramid Lake; they are easily confused with another resident catostomid, the Tahoe sucker. This may, in part, account for the fact that relatively few cui-ui less than 300 mm in length have been identified. Ramsey (letter to E. A. Pyle, 16 September, 1974) offers the following points of contrast between the two larvae:

> *Ventral-Pigmentation*: A consistent character for distinguishing larval stages of Tahoe sucker from larval cui-ui is the presence of a superficial row of melanophores on the midventral skin posterior to the pectoral basis. This abdominal pigmentation is generally absent in cui-ui, although a row of melanophores sometimes is present but confined to the breast anterior to the pectoral bases. The row of midventral melanophores in larval Tahoe suckers is still present at age 66 days (17 to 19 mm total length).
>
> *Intestinal Coiling*: At age 66 days the intestine of the Tahoe sucker loops far anterior in contrast to the cui-ui, where it is either straight or has a left twist.
>
> *Mouth*: The lips of the Tahoe sucker are thicker and the mouth is placed further ventrally than in the cui-ui.
>
> *Other*: A character sometimes useful at ages earlier than 66 days is the presence in cui-ui of a depigmented "one to one" on top of the head, just posterior to the eyes. There is considerable occluding of this pigmentation by age 66 days.

Snyder (1981a, 1981b, 1983) studying larval development of cui-ui in comparison to the other catostomids that spawn in the Truckee River system, i.e., Tahoe sucker and mountain sucker, developed a taxonomic key that separates the larvae and early juveniles of the three species. Snyder concludes the larvae can be separated on the basis of midventral pigmentation, peritoneal pigmentation, gut-loop formation, and mouth characters.

The following differential characteristics are included to complement previous descriptions of larval development and morphology (Snyder 1983). At a total length (TL) of 11 to 21 mm, cui-ui are characterized by absence of midventral melanophores on the head or abdomen anterior to the bases of pelvic fin or their precursors and anterior to the vent. If midventral melanophores exist, they are present as a short line only in the branchial and heart regions between and anterior to pectoral fin bases. Mesolarvae have a straight gut until about 19 mm TL; metalarvae to 21 mm may develop a primary loop extending forward less than two-thirds of the length of the stomach and not crossing over the stomach. Metalarvae have peritoneal pigmentation largely restricted to the dorsal and dorsalateral visceral cavity.

The following characteristics apply to metalarvae > 21 mm and juveniles < 50 mm. The pigmentation of the peritoneum is mostly lim-

Fig. 5. Adult female cui-ui. Photo by Thomas J. Trelease.

ited to the dorsal and dorsalateral visceral cavity. The primary loop of the gut is relatively straight along the left side of the stomach until about 30 mm TL, at which size secondary loops cross the stomach in an S-shape, persisting through 50 mm TL. The mouth is terminal—usually slightly oblique but sometimes very low and almost horizontal, approaching a subterminal condition.

ADULT MORPHOLOGY

Description

The cui-ui is a large, big-mouthed sucker. The head is wide and somewhat round in cross-section. Its interorbital space is greater than half the length of the head. The mouth is unsuckerlike with a ventro-terminal position. The lips are thin and obscurely papillose. The lower lip is somewhat pendant and divided by a wide median notch. The cui-ui is coarsely scaled, with counts of 13 to 14 above the lateral line, 59 to 66 along the lateral series and 22 to 26 around the caudal peduncle. The total body length is 9 times that of the dorsal fin base. The length of the anal fin, from the insertion to the tip, is about one sixth the total body length. Fin ray counts are: dorsal, 10 to 12; anal, 7; and caudal, 8 or less. The caudal is weak to moderately forked. The caudal peduncle is thick, with the smallest depth going 12 times into standard body length (SL). In triangular section, the pharyngeal teeth are delicate. The last pharyngeal arch bears a row of more than 10 comblike teeth confined to a single row. The swim bladder is 2–celled; the peritoneum is nearly black. Each gill raker is branched like broccoli (Fig. 5).

Sexual Dimorphism

Breeding males display a brilliant red to brassy color on the sides; in general they are black or brown above, fading into flat white below. Females have a bluish gray cast yearround. Female cui-ui attain greater length and heavier weight than males. During the spawning season the vent of females becomes swollen and extended, whereas males develop nuptial tubercles on their fins. Apparent sexual dimorphism exists in the meristics associated with fin size (Table 3). The length of the base of the dorsal and anal fins, the height of the dorsal and anal fins, and the length of the pectoral, pelvic, and caudal fins are all proportionally greater for males. Snyder (1918) refers to differences between the sexes:

> The females are more stocky than the males, and with their huge heads, large rounded bodies, and relatively

Table 3. Meristics of *Chasmistes cujus* from near the mouth of the Truckee River (Snyder 1918).

Morphological characteristic	Mean measurement	
	Males n=11	Females n=7
Standard length (mm) ***	427.1	487.3
range	(410–444)	(445–538)
Percent of body length		
Length head	28.0	27.8
Depth body *	21.1	22.4
Depth caudal peduncle	8.5	8.2
Length caudal peduncle	15.8	15.2
Length snout	12.9	13.2
Diameter eye	3.1	2.9
Interorbital width	12.4	12.5
Depth head	18.7	18.6
Snout to occiput	22.3	22.0
Snout to dorsal	51.3	50.5
Snout to ventral	58.1	58.4
Length base of dorsal ***	15.1	13.3
Length base of anal ***	9.4	8.1
Height dorsal	12.9	12.5
Height anal ***	19.9	15.6
Length pectoral **	18.9	17.5
Length pelvic ***	13.8	11.6
Length caudal ***	20.4	18.4
Dorsal rays	11.1	10.7
Anal rays	7.2	7.0
Scales lateral line	62.1	61.6
Scales above lateral line	13.6	13.9
Scales below lateral line	10.4	10.1
Scales before dorsal	31.6	30.3

* Significant differences between sexes, $P<0.05$.
** $P<.01$
*** $P<.001$

short fins are very ungainly looking fish. The scales and fins are without tubercles.

Snyder (1918) describes the differential coloration patterns between the sexes. He also reports that Indians could differentiate cui-ui from Pyramid and Winnemucca lakes by the grayer color of the Winnemucca cui-ui, although he was unable to detect any difference.

Comparative Morphology

The ventro-terminal position of the mouth is a diagnostic characteristic of *Chasmistes* spp. It is so exceptional among the usually ventral-mouthed sucker family that it has been regarded as an extreme specialization; however, certain primitive suckers (e.g., *Amyzon* and *Ictiobus cyprinellus*) and presumed sucker ancestors are also characterized by relatively terminal mouths (Miller and Smith 1981). Cui-ui is the largest living species of *Chasmistes*. Snyder (1918) collected specimens ranging from 410 to 670 mm in SL.

Of various adult meristic data summarized from the literature, Snyder (1983) determined that lateral series scale counts prove to be diagnostic in separating cui-ui (59 to 66) from mountain sucker (75 to 100) and Tahoe sucker (79 to 95). For juveniles, Snyder found this character useful only when squamation is complete, usually by 35 to 50 mm TL.

The comparative morphology of Catostomidae has been studied with reference to the swim bladder (Nelson 1961), the opercular series (Nelson 1949), the Weberian apparatus (Nelson 1948), and the brain and lips (Miller and Evans 1965). *Chasmistes* spp. have a two-chambered swim bladder that is characteristic of all catostomids except *Moxostoma*, which has a three-chambered structure. It is the posterior chamber in catostomids that regulates buoyancy. The usual catostomid swim bladder is 35 to 45% of the SL of the fish (7% by volume); however, the cui-ui swim bladder is only 32.1% of SL (Nelson 1961).

Nelson (1949) presents a generalized composite of the catostomid opercular series, which consists of a large operculum, relatively small suboperculum and interoperculum, and invariably three branchiostegal rays. On the basis of the opercular series, the genera of Catostomidae can be arranged into three well-defined groups; *Chasmistes* belongs to the group including *Catostomus* and *Xyrauchen* (Nelson 1949).

The Weberian apparatus of catostomids includes the first four vertebrae and associated structures that form two separate functional units. *Chasmistes* has the same general morphological pattern as *Catostomus* and *Xyrauchen*; however, it differs in having enlarged esophageal supports and obliterated second to third intervertebral space (Nelson 1948). Based on the comparative morphology of the Weberian apparatus, Nelson concludes *Chasmistes* is an early divergent of the catostomid stock.

Miller and Evans (1965), studying the morphology of the brain and lips in catostomids, conclude:

> Their principal value probably lies in providing a basis for making inferences about the life history, and especially the habitat preferences and feeding behavior of little-known species.

Thus, morphological evidence may shed light on aspects of the ecology of cui-ui about which there has been much speculation. The facial lobe of the brain is associated with taste buds on the lips and skin, whereas the vagal lobes receive fibers from taste buds in the mouth and pharynx. The brain morphology of cui-ui is unique in several ways: the optic lobes are small and separated, the postcerebellar medulla is elongated, and the vagal lobes are well developed but located more posteriorly than is usual in catostomids. The overall pattern suggests a well-developed "mouth tasting" apparatus (Miller and Evans 1965). Suckers that have large vagal lobes are characteristic of lotic habitats, and mouth tasters probably sort food within the oral cavity. Thus the cui-ui is probably not a sight-feeder in surface waters but may use the oral cavity to sort out food (e.g., algae and invertebrates). Other genera with well-developed vagal lobes include *Xyrauchen*, *Ictiobus*, and *Carpiodes*.

Age and Growth

The cui-ui is a slow-growing, long-lived fish, living 18 or more years (Robertson 1979). Scoppettone (report to Desert Fishes Council 1983) stated it may live much longer (≥ 40). Growth in length is rapid for the first 4 to 5 years and slower thereafter. Annuli in older fish are formed between June and August; in younger fish it may occur the first week of June.

Back-calculated fork length (FL) at scale formation is 46.0 mm for known age fish (I to III), from the NFG Washoe Rearing Station, Reno. The calculated FL was skewed substantially higher when advanced age groups (IV and VI) from Pyramid Lake were added. In aquarium-reared fish, E. Pyle (personal communication 1977) found they started forming scales at 49.0 mm FL, and fish 50 mm had from 3 to 7 scales at the base of the caudal peduncle.

Scales are judged not to be reliable for aging cui-ui older than age VI. Other bony parts, otolith, opercula, and fin ray, are more nearly reliable. No technique is reliable when there is no, or almost no, growth and no discernible annulus. This is a definite possibility in older cui-ui. There is reasonably good agreement between fin rays and otoliths and excellent agreement between otoliths and operculum through age XIII (Table 4). There was generally good agreement for otolith, opercula, and scale in age I to IV. Data from opercula were chosen because it is reliable and easy to collect and process. Since growth differences were not significant, sexes are combined (Table 5). The absolute growth is in good agreement with calculated growth (Fig. 6). The body fork length-opercula (X) relationship, sexes combined, is: $FL = 229.2 + 7.0x$ ($r^2 = 0.92$).

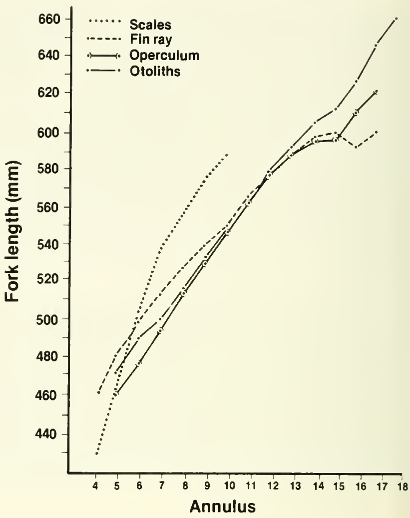

Fig. 6. Absolute growth rates using four methods of age assignment (scales, fin rays, operculum, and otoliths) for cui-ui collected from Pyramid Lake, Nevada, 1978 (Robertson 1979).

The body length–bony part radius regressions are highly correlated: fin ray ($r^2 = 0.93$), opercula ($r^2 = 0.92$), otolith ($r^2 = 0.80$), and scales ($r^2 = 0.63$) (Robertson 1979).

The drop in numbers of fish older than age XV may be attributed largely to natural mortality or no growth, but the low numbers of fish in some of the younger age groups are, in part, a result of moderate to weak year classes (Table 6). Sonnevil (1978) suggests reduced spawning populations and consequent weak year classes can be attributed to reduced river flows at the time cui-ui spawn.

There appears to be good correlation between strength of year classes and flow levels of the river for 5 of the 12 years and poor correlation for 3 of the 12 years (Table 7).

TABLE 4. Comparison of assigned age by various aging methods for 28 cui-ui, sexes combined. Collected April to July 1978 from Pyramid Lake, Nevada.

		Methods of age assignment				
ID#	Fork length (mm) at capture	Scale age	Fin ray age	Operculum age	Otolith age	Centrum age
32A	599	8	10	11	10	—
33A	587	8	11	11	11	—
36A	612	8	12	13	13	—
17A	638	8	13	13	14	—
14B	584	8	—	11	11	—
16B	615	8	11	11	11	—
YY–3	565	8	11	—	12	—
24A	604	8	11	11	11	—
17	578	8	12	12	12	—
24	633	8	15	14	15	—
31	607	8	11	12	12	—
33	618	8	11	12	12	—
9B	588	8	—	11	11	—
20A	618	8	—	14	13	—
21A	615	8	—	12	12	—
28A	591	8	12	12	12	—
8B	588	8	7	12	12	—
4B	620	8	—	13	13	—
27A	648	9	14	14	14	—
38A	632	9	12	13	13	—
19A	609	9	—	11	12	—
AA	610	9	—	12	12	—
F	573	9	—	10	11	10
E	638	9	—	16	16	—
2B	598	—	—	10	10	—
ZZ-B	575	—	—	11	—	—
3B	601	—	—	12	12	—
23	632	—	13	13	13	—

TABLE 5. Calculated average fork length and annual growth increments using opercula of 79 cui-ui, sexes combined. Collected April 1978 to July 1978 from Pyramid Lake, Nevada (Robertson 1979).

Age	Number of	Mean calculated fish length (FL-mm) at each annulus												
group	fish	5	6	7	8	9	10	11	12	13	14	15	16	17
V	13	466												
VI	12	465	490											
VII	3	453	481	499										
X	6	451	470	485	511	527	468							
XI	10	455	477	499	518	539	559	576						
XII	17	453	471	494	512	530	547	563	583					
XIII	10	447	468	492	511	523	546	562	579	596				
XIV	4	455	478	493	515	531	547	566	580	594	611			
XV	1	453	474	495	508	522	529	536	553	564	578	599		
XVI	1	418	440	460	484	508	522	543	564	578	585	599	613	
XVII	2	440	457	471	488	507	524	540	550	564	583	596	610	624
Total number		79	66	54	51	51	51	45	35	18	8	4	3	2
Grand average (mm) calculated fork length		459	475	493	512	530	548	564	578	589	597	598	611	624
Range (mm) in calculated length		418–488	439–529	467–536	484–533	484–571	495–592	515–606	522–634	536–634	553–620	564–627	578–641	592–655
Length increments (mm)		459	16	18	19	18	18	16	14	11	8	1	13	13

Table 6. Age and year class composition of 665 cui-ui sampled in Pyramid Lake, Nevada, 1978 (Robertson 1979).

Age class	Year class	% Composition	Number of fish
IV	1974	6.0	37
V	1973	32.0	211
VI	1972	22.0	149
VII	1971	7.0	49
VIII	1970	5.0	34
IX	1969	3.0	18
X	1968	2.0	16
XI	1967	2.0	14
XII	1966	4.0	27
XIII	1965	4.0	28
XIV	1964	3.0	21
XV	1963	6.0	41
XVI	1962	2.0	13
XVII	1961	0.9	6
XVIII	1960	0.2	1

There appears to be good correlation between strength of year classes and flow levels of the river for 5 of the 12 years and poor correlation for 3 of the 12 years (Table 7).

Table 7. Discharge in cubic feet per second (cfs), of the Truckee River near Nixon, Nevada, for the calendar years 1962–1973 (USGS 1962–1973) and year class–levels of flow relationship.

Year	Age group	Mean flows (cfs) by month April	May	June	July	Strength of year class*	Level of river flows*
1962	XVI	315.0	229.0	31.3	18.8	1	3
1963	XV	183.0	1391.0	926.0	53.7	1	2
1964	XIV	53.4	93.2	48.3	26.2	3	3
1965	XIII	580.0	1325.0	515.0	62.2	2	1
1966	XII	64.6	61.4	47.0	33.2	2	1
1967	XI	5.9	7.5	11.4	31.7	3	3
1968	X	321.0	67.9	52.4	38.8	3	3
1969	IX	3392.0	3454.0	3469.0	430.0	3	1
1970	VIII	530.0	212.0	291.0	445.0	2	2
1971	VII	770.0	1234.0	1744.0	451.0	2	1
1972	VI	236.0	249.0	110.0	43.3	1	3
1973	V	854.0	991.0	453.0	321.0	1	1

*Rated on a 1 to 3 scale, where 1 is strong and 3 is weak.

Although 1969 was a high water year, a weak year class resulted. According to Robertson (1979), this appears to contradict the hypothesis of high flows and successful cui-ui spawning; however, it is pointed out this was the year of exceptionally high suspended sediment discharges, which may have been lethal to fertilized eggs.

Koch (1972) reports the mean age of spawning cui-ui in 1971 and 1972 as 7.5 and 7 years, respectively. These represent the strong year classes produced in high water years of 1963 and 1965. Koch also found a low number of fish representing ages IV, V, and VI in 1971 and 1972.

Robertson (1979) determined the length-weight relationship for 139 females, ranging from 453 to 653 mm FL, and for 147 males, ranging from 448 to 577 mm FL. Only spawned fish were included in these data. The relationships for males and females are: males $\log_{10} W = 3.4725 + 2.4639 (\log_{10} L)$ ($r^2 = 0.77$); females $\log_{10} W = 4.5046 + 2.8485 (\log_{10} L)$ ($r^2 = 0.93$). Males weighed less than females of equivalent length and age. This is in agreement with Johnson (1958) and Koch (1972). The length-weight relationship in the 1975 to 1977 Pyramid Lake study (Robertson and Koch 1978) was: $\log_{10} W = -1.240 + 2.5738 (\log_{10} L)$; this is in agreement with work done by Robertson (1979) in 1978–1979.

The condition factor, or general robustness of the fish, K(FL) for spent (spawned out) fish ranged between 1.08 and 1.64, with a mean of 1.21 for females and 0.81 to 1.61 and a mean of 1.20 for males (Robertson 1979). The condition factor decreases moderately with an increase in length, and the decrease is higher for males than females. Condition factors for the 1976 to 1977 study showed similar trends (Table 8).

Food and Feeding

The diet of cui-ui is not well known; however, we made some observations under artificial conditions. Koch (1972, 1976) reports larval cui-ui, older than 20 days, readily consume zooplankton introduced into an aquar-

TABLE 8. Length, weight, and condition factors $K = W \times \frac{10^5}{FL^3}$ for cui-ui, sexes combined, Pyramid Lake, Nevada, 1976 to 1977 (Robertson and Koch 1978).

Fork length (mm)	Weight (g)	K factor
378	566	1.04
401	659	1.02
424	761	0.99
447	872	0.97
472	1002	0.95
495	1133	0.93
518	1273	0.91
544	1444	0.89
589	1771	0.86

ium of lake water. He reports the zooplankter *Moina hutchinsoni* is most preferred by larvae, presumably because it has limited mobility, whereas *Diaptomus sicilis* is the least preferred zooplankter (Fig. 7). We have observed aquaria-reared larvae and juvenile cui-ui grazing on periphyton growing on rocks. Since zooplankton is not abundant in the river habitat of larval cui-ui, periphyton is probably important in their diet. When young cui-ui first enter the lake, they may feed both on periphyton and zooplankton. In the David L. Koch Hatchery larval and juvenile cui-ui feed on algae on the sides of the tanks, as well as on commercial fish feed (A. Ruger personal communication 1983).

Snyder (1918) found spawning adults do not feed; he states: "The stomachs of all specimens examined were devoid of food." Koch (1972) reports cui-ui examined during spawning migrations of 1971 and 1972 had not recently fed. Examination of fish during the spawning migration at the Marble Bluff facility also confirm these observations.

Johnson (1958) reports that, of 46 adult cui-ui examined, 43 had eaten zooplankton (93.5% occurrence), 4 sand and mud (8.7% occurrence), 2 unidentified material (4.3% occurrence), and 1 insects (2.1% occurrence). La Rivers (1962) reports T. J. Trelease examined specimens taken in commercial net hauls and found a mixture of algal filaments with zooplankton fragments. From this information La Rivers (1962) concludes, "It seems probable that most of the feeding is done about rocks where thick algae coatings are heavily populated with micro-crustacea." Based on the cui-ui's fine and numerous gill rakers, La Rivers hypothesized, "The strong possibility exists that they can extract useable quantities of micro-crustacea from the open lake waters." T. J. Trelease (personal communication 1984) observed cui-ui in large doughnut-shaped schools near the surface over deep water and far from shore first in 1954. He assumed they were feeding since tui chub form similarly shaped schools when they are feeding. He saw these schools somewhat frequently as late as 1968. Vigg (1978a, 1980) documented that adult cui-ui primarily inhabit the shallow benthic areas and not the limnetic water column. It may be that when they inhabit the benthic zone they generally feed further off the bottom than species of suckers with ventral mouths.

Fig. 7. An adult copepod, *Diaptomus sicilis*, a common food of cui-ui.

REPRODUCTION

Migration

Snyder (1918) and Scoppettone et al. (1981, 1983) made detailed observations on cui-ui spawning migrations. Snyder observed the annual cui-ui spawning run begins about April 15, depending on the condition of the river. La Rivers (1962) states it is about a month later than in Snyder's time as a result of river conditions: it extends from mid-May to early June. However, Trelease (1971) reports cui-ui may spawn as early as April and as late as July, when a surge of fresh water often triggers the spawning run. The cui-ui apparently homes fresh water, including springs. Scoppettone et al. (1981) also found a sudden heavy surge of very turbulent water often triggered spawning activities, even in the daytime. The cui-ui prefers depths of water for spawning that range from 9 to 43 cm, velocities that range from 23 to 87 cm/sec, and substrate with about 60% gravel.

Historically, cui-ui spawning runs up the Truckee River only occasionally reached downtown Reno, a distance of over 100 km (Snyder 1918). Today they generally run no farther upstream than 15 to 20 km, although they can go further. Koch and Contreras (1972) report spawn-laden cui-ui reach exhaustion in 18, 10, 2, and 0.5 hours at velocities of 1.2, 1.8, 4.6 and 5.2 m/s, respectively.

Spawning Behavior

Spawning cui-ui often choose the head of gravel bars, where the flow is rapid and the substrate relatively free of silt (McGarvey 1974). At times the dorsal fins of the cui-ui project above the water, and in very shallow places, where there is much crowding, the entire backs of the fish are exposed (La Rivers 1962). Trelease (1971) notes the numbers of cui-ui at the mouth of the Truckee River in past years were so immense at spawning time that fish near the surface were literally forced out of the water, and during periods of peak activity schools of fish covering 0.4 ha or more would form a mass of writhing fish on the surface of the water. Some runs of cui-ui were so extensive that, as fish worked their way upstream in dense schools, their numbers actually blocked the flow of water and diverted it around them. As a result, a new channel was sometimes cut through the sandy delta, leaving large numbers of fish stranded.

Migrating and spawning cui-ui are more active at night than in daytime (Snyder 1918). Scoppettone et al. (1983) found that peak spawning occurs between the hours 2000 and 0600 over a 3–day period and postulate that nocturnal spawning lessens egg predation. Adhesive eggs are broadcast over a large area (Koch 1973). One spawning act, lasting from 3 to 6 seconds, is participated in by 1, or occasionally 2, females and from 2 to 4 males; although a typical spawning act has 1 female and 2 males. Scoppettone et al. (1983) found the most active male spawned 294 times, the most active female 114 times. The length of the spawning run for individual males was 3 to 5 days, for females 2.5 to 4 days.

Just prior to spawning, two males position themselves on either side of a female, the heads of the males just aft of the female's head. With bodies touching and quivering, the female deposits eggs, followed by the males expelling sperm. The cupping and vibration of the male's caudal, along with the female's caudal, creates an eddy preventing the eggs from drifting away before they are fertilized (Scoppettone et al. 1983). Although the cui-ui does not build a nest, the fanning of the caudal fins serves to clear the area of silt.

Optimum Hatching Temperature

In an 8–day period when temperatures ranged from 13.8 to 20.8 C, with a mean of 16.7 C, mean viability of the embryos was 47% (Scoppettone et al. 1981). Koch (1981) found 13.9 C optimum for cui-ui egg incubation; embryos incubated at 17.8 C had a 60% survival to hatching, whereas embryos incubated at 21.7 C had a 30% survival. High temperatures cause preemergence of larva, and a lower rate of survival (Lockheed Ocean Sciences Laboratories 1982).

Larval Migration

Larval peak downstream migration is 14 or more days after hatching (Scoppettone et al. 1983). Hatchery-reared larval cui-ui, 15 to 18 days old, released in 3 areas of the Truckee River, began migrating downstream immediately. The peak migration occurred the night of release followed by several days' lull. All three groups showed a tendency for immediate outmigration (Scoppettone et al. 1981). It should be noted that our embryological studies show that larvae are not developed well enough to feed or swim actively before 21 to 18 days at 13.6 C. It may be that early migrations (< 28 days) greatly reduce chances of survival.

Lake Spawning

There are several reports of cui-ui spawning in the freshwater–lake saline interface. Snyder (1918) reports, "On May 1, 1913 large numbers of cui-ui were found depositing eggs along the shallows near some springs on the southwest shore." Johnson (1958) observed ready-to-spawn cui-ui around the periphery of the lake. Koch (1973) documented the spawning behavior of cui-ui near the inflow of freshwater springs (0.014 cms) in 17.3 C lake

TABLE 9. Number of cui-ui eggs taken at the Marble Bluff facility, 1978–1983 (Source: Alan Ruger, Pyramid Lake Fisheries director).

	Number of spawners		Number of eggs	Eggs per female
	Male	Female		
1978	188	226	4,838,660	21,410
1979	112	92	2,706,308	29,416
1980	333	320	12,140,480	37,939
1981	166	158	5,437,886	34,417
1982	422	436	17,707,268	40,613
1983	184	244	13,706,700	56,175
Totals and weighted average	1,405	1,476	56,537,197	38,304

water in the Hell's Kitchen area, which is approximately 29.5 km north of the Truckee River. Most biologists agree that cui-ui spawn in the lake (> 5000 mg/l TDS) as well as in the river (< 600 mg/l TDS), but the success of the lake spawning is not known. Observed lake spawning has been in the vicinity of fresh water, e.g., springs or stream-lake interfaces (Koch 1973). T. J. Trelease (personal communication 1984) lists seven places around the lake where he observed cui-ui spawning over the years. Experiments by LOSL (1982) and Chatto (1979) indicate that eggs must be water hardened in fresh water (< 600 mg/l TDS), or they will either not hatch or the larvae will not survive in lake water. The issue then revolves around the question, Is there enough fresh water in these lake microhabitats for cui-ui eggs to produce healthy larvae? This is a difficult question. According to Chatto (1979), from 2 to 3 days are required if hatching is to be successful. LOSL (1982) declare freshly fertilized eggs are intolerant of 5,897 mg/l of TDS, but within a day the embryos have acquired considerable resistance.

Fecundity

Koch (1972) found cui-ui become sexually mature in their fifth or sixth year and produce 20,000 to 30,000 eggs per year. Frazier and Ferjancic (1977) estimated the average-sized female produced 35,700 eggs. Mean number of eggs per female taken at the Marble Bluff facility from 1978 to 1983 was 36,662 (Table 9). This is a nearly linear increase in the number of eggs/female. This may be due to increased efficiency in egg-taking caused by such factors as riper females, better water conditions, better fish-holding facilities, increased use of hormone injections, and/or increased experience of workers (A. Ruger personal communication 1983). The 1983 value of over 55,000 eggs/female may be more indicative of the actual mean fecundity of the species than lower estimates. The 1983 run was quite different from previous years in timing and size of females. Possibly more large females increased the average number of eggs taken. It is understood that, in the wild, a female would have to spawn several times to reach this number, and realistically this may not happen.

MORBIDITY AND MORTALITY

Large, long-lived cypriniform fishes (such as cui-ui) with relatively small eggs and high fecundity usually experience extremely high mortality rates in their early life stages. At present recruitment is derived from both artificially and naturally reared cui-ui. The hatching success is moderate in the PLF operation, e.g., 75.2% in 1983 (A. Ruger personal communication 1984).

Cui-ui mortality can be divided into five stages: spawning adults, eggs (embryos), larvae, juveniles, and maturing adults. Each stage has differing levels of vulnerability and causes of death. Spawning adults are adversely affected by low flows, high temperatures, and predation. Egg mortality is affected by condition of spawners, high temperatures, and silt. Larvae survival is determined by a complex of factors during their early life in the river, including temperature, flow, food availability, parasites, disease, and predation. In the lake the mortality of juvenile cui-ui is determined by food availability, salinity change, competition, and predation. Nonspawning adults are subject only to mortality factors in the lake environment. Predation there is minimal; therefore, if food supplies are adequate, then parasites, disease, and senility are probably the most significant adverse factors.

Egg and Larvae Mortality

If the Truckee River spawning habitat were optimal, one would expect high hatching success from the river-spawning cui-ui. However, using the fecundity of 35,700 eggs per female estimated by Frazier and Ferjancic (1977), Scoppettone et al. (1981) projected that if 21 females deposited 750,000 eggs only 20,000 larvae would be produced. Their estimated survival rate to emergence is 2.7%, this was attributed to high temperatures, poor egg viability, and predation by Lahontan redsides, *Richardsonius egregius*.

Adult Mortality

The highest adult mortality probably occurs during the spawning season, when cui-ui are most vulnerable to predation. Historically fishing mortality may or may not have been significant; it continued at low levels, as a snag fishery of spawners on and near the Truckee River Delta, until recent years. Since 1979 all fishing for cui-ui, even by tribal members, is prohibited. Death of adults as a result of spawning, as well as handling mortality during and following egg taking at the Marble Bluff and the PLF facilities occurs at unknown levels. Snyder (1918) reports a few dead individuals along the Truckee River after each spawning season, and high mortality regularly occurred at the mouth of Winnemucca Lake. Fish-eating birds, primarily white pelicans, *Pelecanus erythrorhynchos*, double-crested cormorants, *Phalacrocorax auritus*, and California gulls, *Larus californicus*, can wound or kill adult cui-ui. Although large numbers of white pelicans and cormorants were observed on the Truckee River Delta during the 1976 and 1977 cui-ui spawning migration, Knopf and Kennedy (1980) found no evidence that these birds fed on cui-ui. Common carp, *Cyprinus carpio*, and tui chub, *Gila bicolor*, composed over 97% of the diet of the pelican. T. J. Trelease (personal communication 1984) states he has observed pelicans catch and swallow adult cui-ui. The pelicans then had great difficulty taking off with so heavy a load. He also states he has seen several, but not a great many, cui-ui remains on Anahoe Island. He believes the major damage done by birds is pecking out eyes and gills. Pelicans preyed on adult cui-ui during the large run of 1982 (M. LaFever personal communication 1983). This phenomenon was also observed by D. L. Galat in recent years (personal communication 1984). Snyder (1918) reports that when cui-ui migrate in dense schools considerable numbers are crowded into shallow water and even stranded out of water on sand bars:

> Cormorants, gulls, and pelicans in great numbers were attacking them, and many still wriggling fishes had lost their eyes and strips of flesh had been torn from their sides.

Disease

Pathological studies of the wild cui-ui populations have not been conducted; therefore, the effect of internal and external parasites, fungal infestation, and viral and bacterial disease is unknown.

Effects of TDS on Eggs, Larvae, and Juveniles

Bioassay tests conducted by LOSL (1982) demonstrate the intolerance of fertilized and/or water-hardened cui-ui eggs to TDS concentrations above 525 mg/l. Embryos placed in 525 mg/l water (i.e., Truckee River water) for 24–96 hours survived when transferred to Pyramid Lake water (5897 mg/l), although some abnormalities were found. Embryos placed in 5897 mg/l water immediately after fertilization in 525 mg/l water, were atypical within 24 hours. An average 90% mortality occurred in the 5897 mg/l TDS concentration by the third day, and an average of only 8.3% of the embryos in this concentration produced apparently normal fry.

One-day-old cui-ui larvae placed in test concentrations of either 5781 or 3503 mg/l showed differential mortality; 20% and 13.3% of the test fish died in the respective concentrations within 72 hours. Three day old cui-ui larvae placed in test concentrations of 350 and 5781 mg/l had 100% survival in the first 96 hours. After 192 hours there was no mortality in the 350 mg/l level, but the 5781 mg/l level had 7% mortality and an additional 8% abnormalities.

Chronic 180–day tests indicate that reduced survival of juvenile cui-ui, across a broad range of TDS levels extending from 3620 to

5225 mg/l, represents only 33% to 48% of the 96-hour median tolerance limit (LC50). This indicates that, although LC50 tests may show acute toxicity resulting in death only at high TDS levels, lower TDS levels may cause death or abnormalities when fish are exposed for extended periods of time (LOSL 1982).

HABITAT AND ECOLOGY

Physical

At an elevation of 1154.9 m above mean sea level, Pyramid Lake is approximately 40.8 km long and from 5.8 to 17.3 km wide, with a north-south axis (Fig. 1). At this elevation it has a surface area of 437 km^2, a volume of 25.3 km^3, a mean depth of 57.9 m, and a maximum depth of 100.6 m (Harris 1970). The only significant inflow into the lake most years is the Truckee River, which originates 193 km upstream at Lake Tahoe in the Sierra Nevada. During 1976 and 1977 mean surface temperatures ranged from 6.1 to 23.1 C; the lake is monomictic, thermally stratifying in summer and mixing physically during winter. The most characteristic feature of Pyramid Lake is its high TDS—about 5,350 mg/l during 1976–1977. Although sodium chloride is the dominant salt in the TDS (over 70%), the lake is high in bicarbonate alkalinity that is probably important to the ecosystem. Since the baseload of TDS is relatively constant, the TDS of the lake varies with its volume (Benson 1978b).

Temperature

The maximum surface (0 to 1 m) water temperature in Pyramid Lake was 21.4 and 23.1 C in July 1976 and August 1977, respectively (Lider 1978). The lake is thermally stratified from June through December; wind-generated mixing occurs from January through May. A metalimnion forms at depths ranging from 16 to 22 m. The euphotic depth averaged 11 m for 1976 and 1977, which resulted in a trophogenic zone of about 4.67 km^3 (Galat et al. 1981). Dissolved oxygen (DO) at the surface is always near saturation, about 8 mg/l. Metalimnetic and hypolimnetic DO depletion occurs beginning in July, following stratification and algal decomposition. Maximum DO deficits occur in the profundal zone just prior to fall mixing (Sigler et al. 1983).

Plankton

Diatoms *Cyclotella* sp. and *Stephanodiscus* spp. dominate the phytoplankton community during winter; the most abundant chlorophyte, *Crucigenia* sp., attains its maximum abundance in spring. Blue-green algae are by far the dominate phytoplankton in Pyramid Lake (> 74%). *Nodularia spumigena* is the most abundant blue-green algae. Its bloom begins as early as July and last as late as October. Following spring increases of algal growth, orthophosphate and nitrate are depleted and remain at low levels throughout the summer. Silica, in addition to nitrate, probably limits diatom production in Pyramid Lake (Galat et al. 1981). Chironomids are the lake's most abundant macroinvertebrates, followed by oligochaetes, which are especially abundant in the profundal zone (Robertson 1978). Two euryhaline amphipods, *Gammarus lacustris* and *Hyallela azteca*, are associated with tufa and rocks. La Rivers (1962) reports the Mormon creeper, *Ambrysus mormon*, common among the rocks around the periphery of the lake.

The zooplankton community is composed of five cladocerans, three copepods, and four rotifers (Lider and Langdon 1978). The cladoceran, *Diaptomus sicilis*, is a perennial species and the most abundant zooplankton throughout the year.

Factors Affecting Fish Activity

The cui-ui is the least abundant of the four major fish species native to Pyramid Lake. The other three species in increasing order of abundance are Lahontan cutthroat trout, Tahoe sucker, and tui chub. Vigg (1981) estimates cui-ui compose 0.03% by numbers and 0.47% by weight of the fish population. The mean cui-ui catch/gill net set slightly declined from 1976 to 1977 (1.29 to 0.95). This is not a statistically significant decrease ($P = .21$). During 1982 the largest spawning run in five years ascended the Marble Bluff fishway—13,807 cui-ui (Scoppettone personal communication 1983). Although it is not known what proportion this spawning migration represents of the total adult population, now that the fishway is operational at a near constant efficiency, the magnitude of future spawning

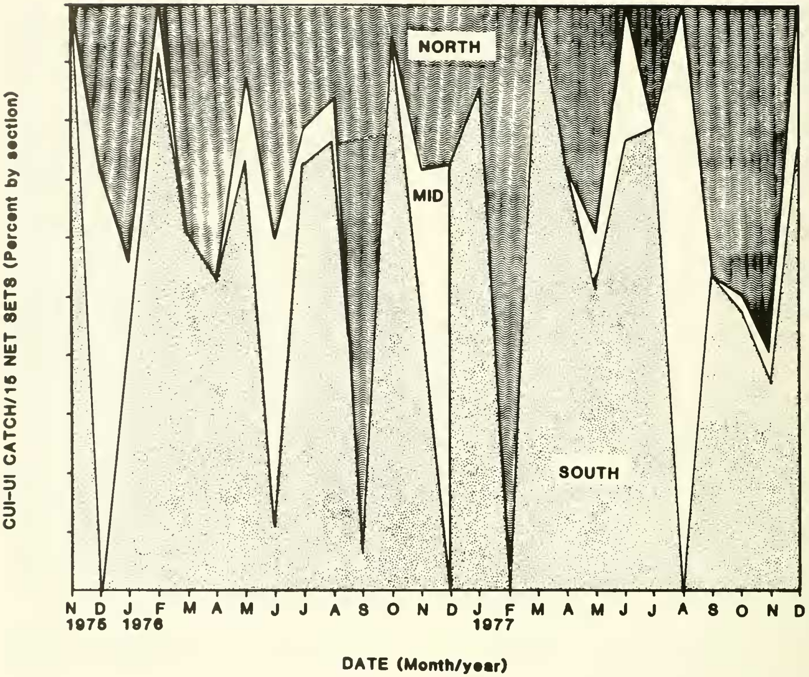

Fig. 8. Proportion of the catch from 15 bottom-set gill nets per month taken in the north (wavy lines), middle (clear), and south (dotted) sections of Pyramid Lake, Nevada, from November 1975 through December 1977.

migrations during years of similar flow regimes will give an indication of cui-ui population trends.

During 1976 and 1977 elevated net catch rates of cui-ui occurred during the spring. There was a concentration in the southern third of the lake during February to May 1976 and March to July 1977 (Fig. 8). Periods of increased proportional catches in the southern section corresponded to a decrease in the relative contribution of the middle third of the lake, with relatively little effect on the catch in the north end. The percent of total was 30, 10, and 60 for the north, middle, and south sections, respectively. The Truckee River delta produced the highest catch rates: 26/net (38.1 m) in May 1976 and 8/net in June 1977. These maxima correspond to the historical spawning period (April to June) and undoubtedly reflect spawning-related activity.

It is a complex of environmental parameters, not just a single variable, that triggers year-round cui-ui activity patterns in Pyramid Lake. We would also expect a multivariate factor to trigger cui-ui spawning runs. Tahoe suckers exhibit a very similar response to the environmental complex in terms of temporal activity (Fig. 9); about 30% of the monthly cui-ui catches can be explained statistically by comparable Tahoe sucker catches ($N = 26$, $P < .01$). This relationship is even more convincing when the spatial effect is included; i.e., 373 individual net samples of the two species in benthic habitats throughout the lake were significantly correlated ($r = .404$, $p < .001$). Thus these two native catostomids are associated in terms of seasonality and habitat.

Environmental variables that can be hypothesized to affect the activity of cui-ui in-

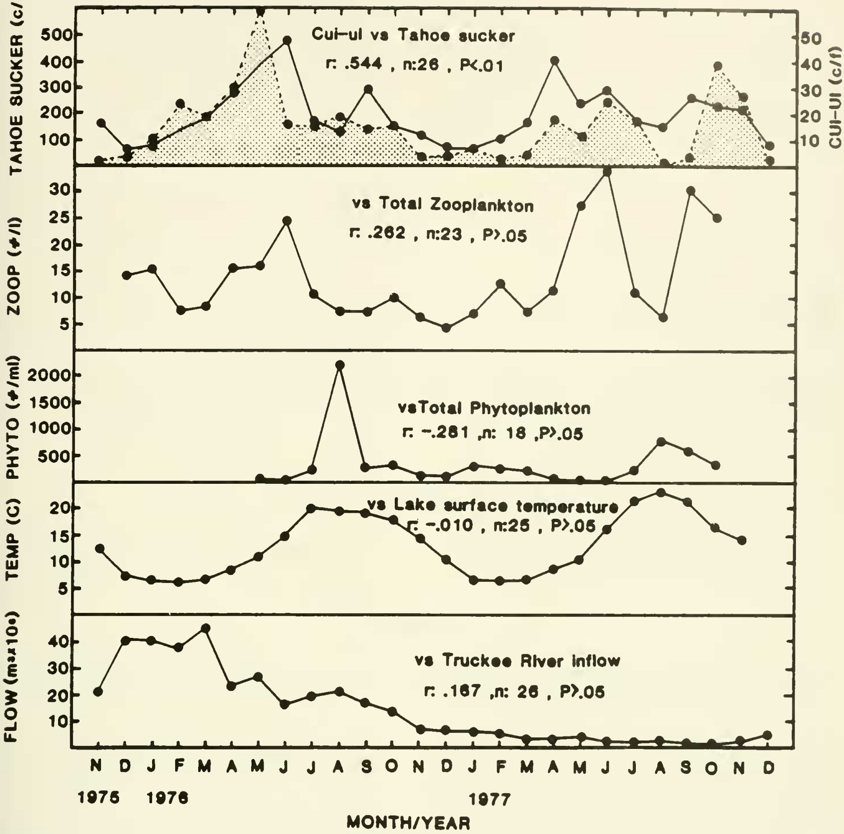

Fig. 9. Comparison of monthly cui-ui catches (shaded) with Tahoe sucker catches, total zooplankton density, lake surface temperature, and monthly Truckee River inflow from November 1975 through December 1977.

clude zooplankton, phytoplankton, lake temperature, and river inflow (Fig. 9). The general pattern of total zooplankton abundance was quite similar to cui-ui activity—unimodal in the spring of 1976 and bimodal in the spring and fall of 1977. The maxima did not correspond exactly, however, and the overall correlation ($r = .262$) was not statistically significant ($P > .05$). Peak phytoplankton concentrations, primarily *Nodularia spumigena*, occurred in June 1976 and August 1977; during these months low numbers of both zooplankton and cui-ui occurred in the samples. The overall correlation between cui-ui and phytoplankton is negative ($r = -.281$) but again not significant. Limited data suggest that cui-ui feed on benthic zooplankton, and *Nodularia* blooms may depress zooplankton populations; therefore these two trophic-related variables may have a cause-effect relationship with cui-ui activity.

It is reasonable to hypothesize that Truckee River inflows affect river spawning-related cui-ui behavior and thus their lakeside activity. The relationship between these variables, however, is very weak ($r = .167$, $P > .05$). The flow regime of 1976 was relatively normal compared to the constant and extremely low flows of 1977. This situation provides an illuminating comparison: in 1976 peak cui-ui ac-

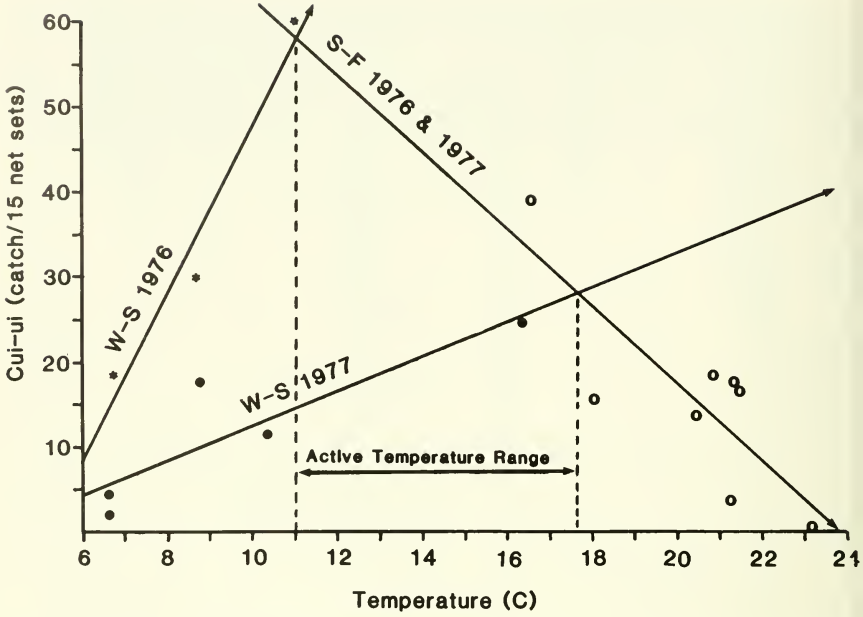

Fig. 10. Direct linear relationships (P<.05) between cui-ui catches and surface lake temperature during the winter-spring (W-S) periods of 1976 (asterisks) and 1977 (solid circles) compared to the inverse linear relationships (p<.05) during the summer-fall (S-F) periods of 1976 and 1977 combined (open circles).

tivity in the lake occurred in May as flows began to subside after four months of high flows. In 1977 cui-ui activity again peaked in the spring in spite of the fact that river flows had been negligible for over seven months. This limited observation may illustrate that cui-ui have an innate response to spring environmental conditions that is not totally dependent on high river flows. It is notable, however, that the magnitude of the 1977 cui-ui activity peak was much less than 1976 and had a different pattern (bimodal).

Water temperature is another variable that is generally associated with the activity of spring-spawning fishes. There was no linear correlation, however, with lakewide cui-ui activity and the surface temperature of the lake (r = −.010, P > .05). The explanation for this apparent anomaly is that the relationship is quadratic, not linear. During spring, as water temperature increases from winter minima, cui-ui activity increases in a direct relationship. As temperature continues to increase during the summer past a threshold value, cui-ui catches decline. This relationship is illustrated by Fig. 10; the temperature threshold was 11.0 C in 1976 and 17.6 in 1977. Thus the temperature range of maximum cui-ui activity during the winter-spring period of increase and summer-fall maximum temperature decrease regime was 11.0 to 17.6 during 1976–1977. Photoperiod may also have an (unmeasured) effect on the prespawning migration of cui-ui.

Cui-ui catches varied significantly by season and depth for both 1976 and 1977 (P < .001). Maximum densities of cui-ui occurred in the inshore benthic zone from 0 to 15 m in depth, i.e., 2.0 fish/net (Table 10). Catch/effort progressively decreased in benthic areas at depths of 23 and 46 m. No cui-ui was captured at depths 46 m, nor at the surface inshore, nor in the deep water column offshore. These distribution patterns are similar to the Tahoe

TABLE 10. Distribution of 421 adult cui-ui captured in six depth-stratified habitats of Pyramid Lake with experimental gill nets from November 1975 through December 1977 (Vigg 1980).

	Depth (m)	Number of samples	Cui-ui Number	Cui-ui Catch/effort
Inshore benthic:	0–15	199	400	2.01
	23	35	10	0.29
Offshore benthic:	46	152	11	0.07
	46–100	72	0	0
Surface inshore:	0–2	35	0	0
Water column offshore:	0–46	18	0	0

sucker, but according to net catches the cui-ui is apparently more inshore oriented (Vigg 1978a, 1978b, 1980). This does not overlook the fact that in the past large schools of surface-feeding cui-ui were observed over deep water and away from shore.

IMPORTANCE TO NATIVE AMERICANS

Native Americans inhabited the Lake Lahontan ecosystem from at least 11,250 ± 250 radiocarbon years BP, as indicated from artifacts in the Winnemucca Lake basin (Hattori 1982). When the Indians arrived, Lake Lahontan occupied much of western Nevada (Russell 1885, Benson 1978a). Follett (1982) identified remains of four fish species at the Falcon Hill archaeological site, northwest of Winnemucca Lake: cui-ui, Tahoe sucker, Lahontan cutthroat trout, and tui chub; the earliest materials associated with fish remains were radiocarbon dated at 9540 ± 120 radiocarbon years BP. D. R. Tuohy, curator of archaeology, Nevada State Museum, conducted extensive studies of human habitation in the Pyramid Lake basin; his data indicate that between 9500 and 500 BP at least 3 different prehistoric human cultures inhabited the region. The latest culture, the Northern Paiute, live in the vicinity of Pyramid Lake.

The cui-ui at one time constituted the principal food of the Northern Paiute around Pyramid and Winnemucca lakes (Powers 1877). The fact that the Pyramid Lake Paiutes were called kuyuidikadi or kuyuitakuda (eaters of cui-ui) indicates the importance of this fish to the tribe's culture and sustenance. Snyder (1918) reports Pyramid Lake Indians preferred cui-ui to trout. Bath (1978) reports cui-ui were preferred because, unlike trout, they could be dried in the sun and thus preserved for later use. Information collected by Stephen Powers (cited by Fowler and Bath 1981) indicate Tahoe suckers were also eaten regularly, but they were not as favored as cui-ui or trout. For example, a collection from Thea Heye Cave near the southern end of Pyramid Lake contained the desiccated remains of nine or more cui-ui but only one Tahoe sucker (Follett 1977). Pyramid Lake Indians made elaborate adaptations to various components of their wetlands, but they concentrated on the capture of Lahontan cutthroat trout and cui-ui (Harner 1974). The Pyramid Lake Paiutes resisted all attempts by the federal government to turn them into irrigation agriculturalists and instead actively pursued subsistence fishing (Knack 1982).

Elaborate techniques were utilized by Indians to capture fish (Fowler and Bath 1981). Fishing was a year-round subsistence activity at Pyramid Lake and could be separated into river and lake fishing (Bath 1978). River fishing could be further subdivided into (1) exploitation of spawning runs (high water) and (2) low-water fishing. Lake fishing was an individual enterprise practiced during the summer and early fall and accomplished with set lines (for trout), gill nets, harpoons, and spears (Fowler and Bath 1981). However, baited hooks were probably not used for cui-ui. Large treble hooks were utilized at one time to snag cui-ui congregated at the delta.

Cui-ui were caught in large quantities and played an important role in the historic economy of the Pyramid Lake Tribe as a trade item. Follett (1980) reports cui-ui remains at the Karlo Site, about 24 km north of Honey Lake, California. Archaeological sites in Nevada where cui-ui remains have been found include: Humboldt Cave and Humboldt Sink (Hubbs and Miller 1948, Heizer and Krieger

1956), Fishbone Cave and Winnemucca Lake (Orr 1956), Lovelock Cave and Humboldt Sink (Follett 1967, 1970), the Nicolarsen Site at Winnemucca Lake (Follett 1974), Thea Heye Cave at Marble Bluff, Pyramid Lake (Follett 1977), and Falcon Hill (Follett 1982). The Pyramid Lake Tribe was the most widely known band of Northern Paiute. The Paiute name was familiar to Indians from Burns, Oregon, to Owens Lake, California, a distance of more than 805 km (Stewart 1939).

T. J. Trelease (personal communication 1984), who talked to many of the older Paiutes and other local people (some whose observations date back to 1906), believes the cui-ui and trout were taken by Indians in large numbers only during spawning runs. These harvests were so plentiful that they lasted for many months. The tui chub, however, was captured year-round, except during the more severe winter weather, and was a staple in the diet. It was taken from the lake in sagebrush bark nets and by hook and line. Some of the informants Trelease mentioned were Phil Orr, Margaret (Peggy) Wheat and L. W. Morgan.

Spawning runs of cui-ui during high water were fished using platforms with lifting nets, with or without weirs (Fowler and Bath 1981). Sturdy winter platforms were built by several men who shared trout fishing privileges. Spring and summer platforms operated by individuals were less substantial. During summer and early fall, as well as winter, when flow was low and the water clear, harpoons and spears were used (Fowler and Bath 1981). Trelease (personal communication 1984), quoting L. W. Morgan, describes an Indian family fishing expedition sometime between 1906 and 1910 as follows: the father, using a gaff-hook fastened to a long pole, stood in waist-deep water and snagged cui-ui, which were tossed up on the bank. Mother and children built drying racks, cleaned the fish, and put them out to dry. Sometimes platforms were used in conjunction with weirs that directed fish over an area of river bottom paved with white rocks to improve visibility; the lighter bottom also facilitated night fishing.

The fishing technology used by the Walker Lake Northern Paiutes, and at least to some degree by the Carson Lake and Humboldt Basin groups was similar to that of the Pyramid Lake Indians (Speth 1969). Fowler and Bath (1981) conclude native Americans in the western Great Basin have been involved in fishing complexes of various orders and varying degrees for several millenia.

Knack (1982) reports that efficient methods utilized by the Pyramid Lake Paiutes to capture cui-ui and Lahontan cutthroat trout during their spawning runs were unacceptable to the Nevada legislature, which "imposed a definition of appropriate sporting technique, which was derived from the Anglo-European cultural past." Knack (1982) summarized the fishing laws the state of Nevada passed affecting the Indians:

> For over one hundred years, the state of Nevada attempted to impose its laws on the Northern Paiutes of Pyramid Lake. It declared which fish could be caught and where, as well as the techniques to be used. At first, the state tried simply to assume jurisdiction over Indians living on reservations, and then it employed a series of circumventions. Indians were cut off from sales markets and arrested as soon as they left federal trust land. Indian agents were encouraged to enforce state law on the reservation itself. The opportunity to commercialize the one productive resource of the reservation was denied Paiutes by the imposition of state law; economic development was thereby blunted, prosperity stopped, and the local economy allowed to stagnate. Meanwhile, Anglo economic developments, dependent on water diversions to agriculture, mining, and urban areas, produced drastic changes in the fishery population. The state defined fish as a luxury suitable only for sport, and subsequent Anglo actions assured that this would be so.

Trelease (personal communication 1984) strongly disagrees with Knack. He believes the state had only the welfare of the resource in mind, and the federal government, whose responsibility it was, did nothing.

Townley (1980) documents the historical devastation of the Truckee River, the Pyramid Lake trout and cui-ui fishery, and the attitudes of the various sides of the controversy. Snyder (1918) enunciated the attitude of those who believed that the fishery, so important to the livelihood of the Pyramid Lake Indians, could not stand in the way of white man's progress:

> A discussion of the economic value of the fishes of this region and any consideration of methods of propagation and protection must begin and end with the assumption that agricultural and manufacturing interests are of paramount importance. A considerable and constantly increasing amount of the flowing water must be used first for power and then for irrigation, and when any measure intended for the protection of fishes is found to seriously interfere with the working of power plants or the demands of agriculture it will have to be abandoned.

Fortunately for fishery resources in general and the cui-ui in particular, society is evolving a philosophy more compatible with the maintenance of renewable natural resources. Through federal laws, especially the Endangered Species Act, the cui-ui is deemed to be important to society as a whole.

MANAGEMENT

The primary management objective for the cui-ui is the restoration of a stable, naturally reproducing population, thereby allowing its removal from the endangered and threatened species list. This can best be done by increasing numbers substantially and by improving habitat. Ongoing programs designed to reduce man-induced threats to the cui-ui population in Pyramid Lake include: (1) maintenance of water temperatures $\leq$ 13.9 C during spawning, made possible by maintaining adequate flows and shading of the river; (2) renovation of the lower Truckee River so that it has a stable meandering channel and riparian habitat of trees and shrubs; (3) artificial propagation; (4) use of the Marble Bluff Dam and Fishway for monitoring the spawning population, collecting eggs, and providing spawner access to the Truckee River; (5) maintenance of the fishway at Numana Dam to provide spawning access further upriver; (6) continuation of life history studies.

The lower Truckee River temperatures fluctuate with flow, time of day, season, and year. The optimum temperature for cui-ui spawning and egg hatching is 13.9 C. The lower river has a scouring, braided, exposed channel; the need is for a meandering, stable channel and banks that stand firm, with trees and shrubs for shading (Gregory 1982). The impoundment above Marble Bluff Dam has a population of predatory fish including sunfishes and one or more species of catfish. This poses a problem for larval cui-ui that migrate downstream primarily at night. Removal or depletion of predators is a possible answer. In very low water years these larvae may also become disoriented in the impoundment.

The tribe's Pyramid Lake Fisheries organization is rearing millions of cui-ui fry annually, some stocked in Pyramid Lake and in the Truckee River. In 1982, a high water year, more than 11,000 adult cui-ui went up the fishway to spawning sites in the river (13,807 reached the trapping facility). Life history studies have and are exploring stages in the life of the fish and their current and optimum habitat. Artificial propagation should be continued until the number of adult cui-ui in Pyramid Lake is at or near their optimum, if not historic, numbers. Barring disaster, the natural runs should then be able to maintain adequate numbers.

The base load of TDS is essentially static in Pyramid Lake (Benson 1978b). This means the concentration varies inversely with the volume of the lake. The concentration of TDS in Pyramid Lake should not be allowed to increase appreciably; current levels are at or above optimum for cui-ui. The lake levels should not fluctuate beyond a range of plus or minus 3 m except in high water years. Nutrient loading should not be increased from municipal, industrial or agricultural sources.

SUMMARY

The cui-ui, once so abundant that it was a staple in the diet of the Pyramid Lake Paiute Indians and an item of trade, is today endangered. It is a slow-growing, long-lived fish, reaching a length of $>$ 70 cm. Cui-ui eggs must be water-hardened in relatively fresh water. It may or may not be able to spawn successfully in the Truckee River-Pyramid Lake interface, in temporary streams of high water years, or in springs in Pyramid Lake. Biologists are not in firm agreement on these points. Upriver spawning migrations are often, but apparently not always, triggered by surges of fresh water. Spawning starts from mid-April to May and extends through June or, rarely, July.

Modification of the Marble Bluff Fishway provides upstream passage for cui-ui, especially during low water years. Eggs are taken from part of the spawning population; others are allowed to move upstream. Spawning success depends largely on acceptable temperatures and flows. Mortality, primarily from predation, is presumably high on both embryos and larvae in the stream. Once in the lake, young cui-ui undoubtedly face heavy predation. In addition to natural reproduction, millions of larvae are released each year from the David L. Koch Fish Hatchery, Sutcliffe, Nevada.

Cui-ui feed on zooplankton, benthic invertebrates, and algae. They inhabit shallow to medium depth water (< 46 m) in the lake, where they are most active in spring and fall. Adults move into fresh water only to spawn; young cui-ui generally remain in the river for a few weeks after they are hatched.

CONCLUSIONS

The cui-ui is endangered today because of a progressive population decline resulting from transbasin water diversion, failure on the part of the federal government to originally protect the Indians' resources, upstream water use, and early adverse legal and political decisions. Percent of total river flow diversions that began in 1905 reached a climax in the early 1930s, when the combination of low river flows and dropping lake levels caused a delta to form at the mouth of the river. The cui-ui could no longer migrate upstream to spawn; thereafter numbers of adults dropped sharply. To date the population has not stabilized or recovered. Artificial propagation and restoration of river spawning are providing an interim solution. The long-term answer is acceptable spawning habitat: an adequate flow of ≤ 13.9 C water from early to mid-April through June, a stabilized, nonbraided river bed with spawning gravels, and reestablishment of shaded raparian habitat.

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LITERATURE CITED

BATH, J E. 1978. Lake-margin adaptations in Great Basin prehistory. Unpublished Masters of Science thesis. University of Nevada, Reno.

BENSON, L. V. 1978a. Fluctuation in the level of pluvial Lake Lahontan during the last 40,000 years. Quarternary Res. 9:300–318.

———. 1978b. The chemical composition of Pyramid Lake: past, present, and future. Pages 356–413 *in* W. F. Sigler and J. L. Kennedy, eds., Pyramid Lake Ecological Study, W. F. Sigler & Associates Inc., Logan, Utah.

BRES, M. 1978. The embryonic development of the cui-ui, *Chasmistes cujus* (Teleostei, Catostomidae). Unpublished Masters of Science thesis. University of Nevada, Reno. 76 pp.

CARLANDER, K. D. 1969. Handbook of freshwater fisheries biology. Iowa State University Press, Ames. 752 pp.

CHATTO, D. A. 1979. Effects of salinity on hatching success of the cui-ui. Prog. Fish Cult. 41(2):82–85.

COPE, E. D 1883. On the fishes of the recent and pliocene lakes of the western part of the Great Basin, and of the Idaho Pliocene Lake. Proc. Acad. Nat. Sci. Philadelphia. 35:134–166.

FOLLETT, W. I 1963. Preliminary report of fish remains from the Falcon Hill sites, Washoe County, Nevada. Pages 33–34 *in* The 1962 Great Basin Anthropological Conference, Nevada State Museum Anthropological Papers, No. 9. Carson City, Nevada.

———. 1967. Fish remains from coprolites and midden deposits at Lovelock Cave, Churchill County, Nevada. Reports of the Univ. of California Archeol. Surv. 70:93–116.

———. 1970. Fish remains from human coprolites and midden deposits obtained during 1968 and 1969 at Lovelock Cave, Churchill County, Nevada. Contrib. Univ. of California Archeol. Res. Fac. 10:163–175.

———. 1974. Fish remains from site NV-Wa-197, Winnemucca Lake, Nevada. Contrib. Univ. of California Archeol. Res. Fac. 21:37–43.

———. 1977. Fish remains from Thea Heye Cave, NV-Wa-385, Washoe County, Nevada. Contrib. Univ. of California Archeol. Res. Fac. 35:59–80.

———. 1980. Fish remains from the Karlo Site (CA-Las-7), Lassen County, California. J. California Great Basin Anthro. 2 (1):114–122.

______. 1982. An analysis of fish remains from ten archaeological sites at Falcon Hill, Washoe County, Nevada, with notes on fishing practices of the ethnographic Kuyuidikadi Northern Paiute. Appendix A *in* E. M. Hattori, The archaeology of Falcon Hill, Winnemucca Lake, Washoe County, Nevada. Nevada State Museum Anthropological Papers, No. 18. Carson City, Nevada.

FOWLER, C. S., AND J. E. BATH. 1981. Pyramid Lake Northern Paiute fishing: the ethnographic record. J. California Great Basin Anthro. 3(2):176–186.

FRAZIER, J. L., AND K. P. FERJANCIC. 1977. Progress report: cui-ui hatchery operations. Pyramid Lake Indian Tribal Enterprises.

GALAT, D. L. AND W. J. MCCONNELL, eds. 1981. Effects of increasing total dissolved solids on the dynamics of Pyramid Lake microcosm communities. Colorado Coop. Fish. Res. Unit, Colorado State University, Fort Collins. 131 pp.

GALAT, D. L., E. L. LIDER, S. VIGG, AND S. R. ROBERTSON. 1981. Limnology of a large, deep North American terminal lake, Pyramid Lake, Nevada, USA. Hydrobiologia. 82:281–317.

GREGORY, D. I. 1982. Geomorphic study of the lower Truckee River, Washoe County, Nevada. Earth Resources Dept., Colorado State University, Fort Collins. 125 pp.

HARNER, N. S. 1974. Indians of Coo-Yu-ee-Pah, the history of the Pyramid Lake Indians and early tribal history, 1843–1959. Dave's Printing and Publishing, Sparks, Nevada.

HARRIS, E. E. 1970. Reconnaissance bathymetry of Pyramid Lake, Washoe County, Nevada. Hydrologic Investigation Atlas HA-379, U.S. Geol. Surv. 1 p.

HATTORI, E. M. 1982. The archaeology of Falcon Hill, Winnemucca Lake, Washoe County, Nevada. Nevada State Museum Anthrological Papers, No. 18. Carson City, Nevada.

HEIZER, R. F., AND L. K. KRIEGER. 1956. The archaeology of Humboldt Cave, Churchill County, Nevada. Univ. California Pub. Amer. Archaeology and Ethnology 47(1).

HILE, R. 1941. Age and growth of rock bass *Ambloplites rupestris* (Rafinesque) in Nebesh Lake, Wisconsin. Trans. Wis. Acad. Sci., Arts, Lett. 33:189–337.

HUBBS, C. L., AND R. R. MILLER. 1948. The Great Basin with emphasis on glacial and postglacial times. II. The zoological evidence. Univ. of Utah Bull. 38(20):17–166.

JOHNSON, V. K. 1958. Fisheries management report. Lakes—Pyramid, Walker, and Tahoe. Dingell-Johnson Completion Rep. Nevada Fish and Game Department. FAF-4–R. 47 pp.

JONEZ, A. 1955. Pyramid Lake life history of cui-ui. Annual completion report, June 1955. Nevada Fish and Game Commission. FAF-4–R, Job 1–E. 2 pp.

KNACK, M. C. 1982. The effect of Nevada state fishing laws on the Northern Paiutes of Pyramid Lake. Nevada Hist. Soc. Quarterly. 25:251–265.

KNOPF, F. L., AND J. L. KENNEDY. 1980. Foraging sites of White pelicans nesting at Pyramid Lake, Nevada. Western Birds. 11:175–180.

KOCH, D. L. 1972. Life history information on the cui-ui lakesucker (*Chasmistes cujus* Cope, 1883) endemic to Pyramid Lake, Washoe County, Nevada. Unpublished Ph.D. dissertation. University of Nevada, Reno. 343 pp.

______. 1973. Reproductive characteristics of the cui-ui lakesucker (*Chasmistes cujus* Cope) and its spawning behavior in Pyramid Lake, Nevada. Trans. Amer. Fish. Soc. 102(1):145–149.

______. 1976. Life history information on cui-ui lakesucker (*Chasmistes cujus* Cope 1883) in Pyramid Lake, Nevada. Biol. Soc. Nev. Occas. Pap. 40:1–12.

______. 1981. Temperature tolerance evaluations of cui-ui (*Chasmistes cujus*) fertilized eggs and larvae to swimup stage. Report to PLITE. Koch and Associates, Reno, Nevada.

KOCH, D. L., AND G. P. CONTRERAS. 1972. Swimming ability and effects of stress on the cui-ui lakesucker (*Chasmistes cujus* Cope). Biol. Soc. of Nevada, Occ. Pap. 31:1–8.

______. 1973. Hatching technique of the cui-ui lakesucker (*Chasmistes cujus* Cope 1883). Prog. Fish Cult. 34(1):61–63.

KOCH, D. L., J. J. COOPER, E. L. LIDER, R. L. JACOBSON, AND R. J. SPENCER. 1979. Investigations of Walker Lake, Nevada: Dynamic ecological relationships. Desert Res. Inst. Bioresources Center Publications, Reno, Nevada. 191 pp.

LA RIVERS, I. 1962. Fishes and fisheries of Nevada. Nevada Fish and Game Commission, Reno. 782 pp.

LIDER, E. L. 1978. Physical and chemical limnology of Pyramid Lake, Nevada. Pages 157–190 *in* W. F. Sigler and J. L. Kennedy, eds., Pyramid Lake ecological study. W. F. Sigler & Associates Inc., Logan, Utah.

LIDER, E. L., AND R. W. LANGDON. 1978. Plankton ecology. Pages 241–293 *in* W. F. Sigler and J. L. Kennedy, eds., Pyramid Lake ecological study. W. F. Sigler & Associates Inc., Logan, Utah.

LOCKHEED OCEAN SCIENCES LABORATORIES. 1982. Investigation on the effects of total dissolved solids on the principal components of the Pyramid Lake food chain. USDI Bureau of Indian Affairs. Final report. 84 pp.

LONG, W. L., AND W. W. BALLARD. 1976. Normal embryonic stages of the white sucker, *Catostomus commersoni*. Copeia 1976 (2): 342–351.

MCCONNELL, W. J., D. L. GALAT, AND K. HAMILTON-GALAT. 1978. Potential fish production based on organic matter contributions. Colorado Coop. Fish. Res. Unit, Colorado State University, Fort Collins. 84 pp.

MCGARVEY, P. J. 1974. Survival of unique and endangered cui-ui fish enhanced. U.S. Fish Wildl. Serv. News release. 4 pp.

MILLER, R. J., AND H. E. EVANS. 1965. External morphology of the brain and lips in catostomid fishes. Copeia 1965 (4):467–487.

MILLER, R. R., AND G. R. SMITH. 1967. New fossil fishes from Plio-Pleistocene Lake Idaho. Occ. Pap. Mus. Zool. Univ. of Michigan 654:1–24.

______. 1981. Distribution and evolution of *Chasmistes* (Pisces: catostomidae) in western North America. Occ. Pap. Mus. Zool. Univ. of Michigan 696:1–46.

NELSON, E. M. 1948. The comparative morphology of the Weberian apparatus of the Catostomidae and its significance in systematics. J. Morphol. 83:225–251.

______. 1949. The opercular series of the Catostomidae. J. Morphol. 85:559–567.

______. 1961. The comparative morphology of the definitive swim bladder in the Catostomidae. Amer. Midland Nat. 65(1):101–110.

NELSON, L. 1976. SHAD II. A model for analysis of fisheries age and growth data. Wildl. Sci. Dept., Utah State Univ., Logan. 15 pp.

ORR, P. C. 1956. Pleistocene man in fishbone cave, Pershing County, Nevada. Department of Archaeology, Nevada State Museum Bull. 2:1–20.

POWERS, S. 1877. Centennial mission to the Indians of western Nevada and California. Pages 449–460 *in* Annual report of the Board of Regents of the Smithsonian Institution for 1876. U.S. Printing Offices, Washington, D.C.

PYLE, E. A., J. FRAZIER, D. KING, K. JOHNSON, D. LOCKARD, AND T. J. TRELEASE. 1977. Cui-ui recovery plan-draft. U.S. Fish Wildl. Serv., Endangered Species Program. Region I.

RINGO, R. D., AND G. M. SONNEVIL. 1977. Evaluation of Pyramid Lake fishway: operation and fish passage 1976–1977. U.S. Fish and Wildlife Service, Fish. Asst. Office, Reno, Nevada. Special Report. 21 pp.

ROBERTSON, D. A. 1979. Cui-ui investigations: age and growth, Pyramid Lake, 1978. U.S. Fish Wildl. Serv., Fish. Asst. Office, Reno, Nevada. Special Report. 22 pp.

ROBERTSON, D. A., AND D. L. KOCH. 1978. Life history of the cui-ui *Chasmistes cujus* Cope. Pages 51–68 *in* Pyramid Lake ecological study, W. F. Sigler and J. L. Kennedy, eds. W. F. Sigler & Associates Inc., Logan, Utah.

ROBERTSON, S. R. 1978. The distribution and relative abundance of benthic macroinvertebrates in Pyramid Lake, Nevada. Unpublished thesis. University of Nevada, Reno. 68 pp.

RUSSELL, I. C. 1885. Geological history of Lake Lahontan. U.S. Geological Survey Monograph 11. 288 pp.

SCOPPETTONE, G. G., M. COLEMAN, H. BURGE, AND G. WEDEMEYER. 1981. Cui-ui life history: river phase. U.S. Fish Wildl. Serv. Fish. Asst. Office, Reno, Nevada. Annual report. 63 pp.

SCOPPETTONE, G. G., G. A. WEDEMEYER, M. COLEMAN, AND H. BURGE. 1983. Reproduction by the endangered cui-ui in the lower Truckee River. Trans. Amer. Fish. Soc. 112(6):788–793.

SIGLER, W. F. 1951. The life history and management of the mountain whitefish (*Prosopium williamsoni* (Girard)) in Logan River, Utah. Utah State Agric. Col. Bull. 347. 36 pp.

SIGLER, W. F., W. T. HELM, P. A. KUCERA, S. VIGG, AND G. W. WORKMAN. 1983. Life history of the Lahontan cutthroat trout, *Salmo clarki henshawi*, in Pyramid Lake, Nevada. Great Basin Nat. 43(1):1–29.

SIGLER, W. F., AND J. L. KENNEDY, eds. 1978. Pyramid Lake ecological study. W. F. Sigler & Associates Inc., Logan, Utah. 545 pp.

SNYDER, D. E. 1981a. Identification of larval and early juvenile fishes collected from Pyramid Lake and the Truckee River, Nevada, 1973, 1974, 1975, and 1980. Dept. Fish. and Wildl. Bio., Larval Fish Lab. Colorado State University, Fort Collins.

______. 1981b. Developmental study and identification of the catostomid fish larvae of the Truckee River System, final report and key. U.S. Fish and Wildl. Serv. Fish. Asst. Office, Reno, Nevada. 36 pp.

______. 1983. Identification of catostomid larvae in Pyramid Lake and the Truckee River, Nevada. Trans. Amer. Fish. Soc. 112(213):333–348.

SNYDER, J. O. 1918. The fishes of the Lahontan system of Nevada and northeastern California. U.S. Bur. Fish. Bul. 1915–16 (35):31–88.

SONNEVIL, G. M. 1977a. Cui-ui (*Chasmistes cujus*) population monitoring: Pyramid Lake, Nevada 1977. U.S. Fish Wildl. Serv., Fish. Asst. Office, Reno, Nevada. Special report. 6 pp.

______. 1977b. Analysis of catch effort data to reflect the population status of the cui-ui (*Chasmistes cujus*) in Pyramid Lake, Nevada. U.S. Fish Wildl. Serv., Fish. Asst. Office, Reno, Nevada. Special report. 6 pp.

______. 1978. Cui-ui investigations: Pyramid Lake, 1978. U.S. Fish Wildl. Serv. Fish. Asst. Office, Reno, Nevada. Special report. 26 pp.

______. 1981. Evaluation of the cui-ui restoration program: 1977–1980. U.S. Fish Wildl. Serv. Fish. Asst. Office, Reno, Nevada. Special report. 25 pp.

SPENCER, R. J. 1977. Silicate and carbonate sediment-water relationships in Walker Lake, Nevada. Unpublished Masters of Science thesis. University of Nevada, Reno. 98 pp.

SPETH, L. K. 1969. Possible fishing cliques among the Northern Paiutes of the Walker River Reservation, Nevada. Ethnohistory. 16(3):225–244.

STEWART, N. H. 1926. Development, growth, and food habits of the white sucker, *Catostomus commersoni* Le Sueur. Bull. Bur. Fish. 42:147–184.

STEWART, O. C. 1939. The Northern Paiute bands. Univ. of California Anthropological Records. 2 (3).

______. 1941. Culture element distributions: XIV, Northern Paiute. Univ. of California Anthropological Records. 4 (3).

SUMNER, F. H. 1940. The decline of the Pyramid Lake fishery. Trans. Amer. Fish. Soc. 69(1939):216–224.

TESCH, F. W. 1971. Age and growth. Pages 98–131 *in* W. E. Ricker, ed., Methods of assessment of fish production in freshwaters. Blackwell Sci. Publ., Oxford.

TING, P. 1967. A Pyramid Lake surface artifact assemblage located at or near the 3,800–foot elevation. Nevada Archaeological Survey Reporter, Reno. 1(8):4–11.

TOWNLEY, J. M. 1980. The Truckee River Basin Fishery, 1844–1944. Nevada Historical Society in cooperation with Desert Res. Inst., University of Nevada, Reno. 88 pp.

TRELEASE, T. J. 1971. Pyramid Lake's cui-ui—relic of the past. Nev. Outdoors Wildl. Rev. 5(1):26–27.

TUOHY, D. R., AND D. T. CLARK. 1979. Excavations at Marble Bluff Dam and Pyramid Lake Fishway, Nevada, Parts I, II, III, IV, V, and VI. U.S. Dept. Int., Heritage Conservation and Recreation Service. Interagency Archaeological Services. San Francisco, California. 492 pp.

UNITED STATES FISH AND WILDLIFE SERVICE (USDI). 1983. Cui-ui recovery plan (revision). Washington, D.C. 28 pp.

UNITED STATES FISH AND WILDLIFE SERVICE, Nevada Department of Fish and Game, and the California Department of Fish and Game. 1976. Life history and habitat evaluation of the Lahontan cutthroat trout and cui-ui in the Truckee River, October–December 1976. Quarterly Progress Report. Fish. Asst. Office, Reno, Nevada. 14 pp.

VAN OOSTEN, J. 1923. The whitefishes (*Coregonus clupeaformis*). A study of the scales of whitefishes of known ages. Zoologica. 11(17):380–412.

______. 1929. Life history of the lake herring (*Coregonus artedii* LeSueur) of Lake Huron as revealed by its scales, with a critique of the scale method. U.S. Bur. Fish. 44(1928):265–428.

______. 1944. Factors affecting the growth of fish. Trans. Ninth N. Amer. Wildl. Conf. 9:177–183.

VIGG, S. 1978a. Fish ecology. Pages 191–240 *in* W. F. Sigler and J. L. Kennedy, eds., Pyramid Lake Ecological Study. W. F. Sigler & Associates Inc., Logan, Utah.

______. 1978b. Vertical distribution of adult fish in Pyramid Lake, Nevada. Great Basin Nat. 38(4):417–428.

______. 1980. Seasonal benthic distribution of adult fish in Pyramid Lake, Nevada. California Fish and Game 66(1):49–58.

______. 1981. Species composition and relative abundance of adult fish in Pyramid Lake, Nevada. Great Basin Nat. 41(4):395–408.